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OXIDATION SUBSIDENCE AT BISBEE, ARIZONA.[1]

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SUBSIDENCE of overlying rock during oxidation of sulphide replacement ore bodies in limestone, though mentioned in the literature, has been conspicuously neglected as a guide to ore. In Bisbee the writer and his associates undertook its systematic study and found it to exhibit certain simple characteristics identifiable in unmineralized rock as much as 1,000 feet vertically above an ore body.

[1] Subsidence in the overlying rock due to removal of support through shrinkage of ore bodies, and of their walls and floors, during oxidation.

These characteristics resemble those established in subsidence due to mining. In other words, the effects of oxidation shrinkage resemble those of stoping. As the ore, its walls and its floor lose volume during oxidation, the unsupported roof fails, and by the dropping out of blocks from its center, begins to take the form of an arch or dome. Successive doming cracks, one above the other, form curved shells above the ore, and as subsidence proceeds, the cracks open wider and wider and the shells successively fail and break into blocks, which fall from the roof and make a jumble of fragments, large and small, like the filling of a caved stope. These blocks fill the opening, take weight and retard the further opening of the doming cracks above. But the subsidence continues and the stresses caused by it are transmitted higher and higher into the overlying rock. The doming cracks are no longer being strongly developed because the jumbled fill below is supporting the larger part of the weight. But, gradually, cracks of irregular direction extend upward and separate the rock into numerous small blocks. These blocks, though slipping on each other, do not rotate. The slipping is of course downward. It eventually results in a slight subsidence of the whole block overlying the ore and in the development around that block of steep fissures that separate it from the uncracked surrounding rock and outline on the surface the region of subsidence.

The effects more nearly resemble those of mining in which the roof comes down gradually (as in the room and pillar method of coal mining) than they do those of mining in which the roof comes down rapidly (as in the long-wall method); for, instead of showing a pronounced "draw" the limiting side fissures are usually steep and the fissured area on the surface is usually contained within the upward projection of the oxidized area below.

Oxidation subsidence, because of its simplicity and its direct usefulness as a guide to ore, deserves attention in many districts, including not only those in which the ore bodies occur in limestone, but also those with other rocks, in which its effects may be less striking and its study may prove more difficult.

LITERATURE OF OXIDATION SUBSIDENCE.

The following references to oxidation subsidence are not the result of a thorough search of the available literature, but have been picked up here and there, sometimes fortuitously, since the subject has held the attention of the writer. They show clearly, incomplete as they are, that the phenomena of oxidation subsidence have been recognized to some extent for many years.

James W. Malcolmson,[1a] describing the mines of the Sierra Mojada, Mexico, in 1901, made the following statement:

"A noticeable peculiarity in the eastern part of the camp, particularly in the Salvador mine, is the presence of a shattered and completely broken-up limestone roof over the lead-carbonate ores. This shattering appears to have been due to the collapse of the enormous roof after the reduction in bulk of the ore-body, due to oxidation. This disintegration is in places so complete that the lime, over a considerable area, is made up of small angular fragments which sometimes run into the stopes like very coarse sand."

The conditions responsible for oxidation subsidence at Bisbee were described by Ransome [2] in 1904 as follows:

"The most marked physical effect of the oxidation of the ore bodies has been a great increase in the porosity of the masses acted upon. This, by enabling solutions to percolate easily through the partly oxidized zone, has greatly facilitated the migration and concentration of the desulphurized ores and their segregation in workable masses from the bulk of the limonitic and clayey 'ledge matter.'

"The oxidized material is not only more porous but much softer and more plastic than the original mineralized limestone and hence greatly weakens by its presence the rocky structure in which it occurs. The overlying limestones, no longer adequately supported, fissure and settle down upon the soft, plastic ore and gangue. The access of solutions is thus still more facilitated, and the processes of oxidation and solution proceed so much the faster. That part of the surface which is underlain by oxidizing ore bodies is thus rendered less resistant to erosion, other things being equal, than the surrounding country."

[1a] Malcolmson, James W., *Trans. Am. Inst. Min. and Met. Eng.*, vol. XXXII., p. 130. (Mexican Meeting, Nov., 1901.)

[2] Ransome, F. L., "The Geology and Ore Deposits of the Bisbee Quadrangle, Arizona," U. S. Geol. Surv., Prof. Paper 21, p. 159, 1904.

Lindgren,[3] describing the ore deposits of the Tintic district, from field work done in 1911 and 1914, says regarding a cave in the Iron Blossom No. 1 mine:

> The cave in this mine, besides containing limonite stalactites with casts of gypsum, also revealed large masses of gypsum on its bottom, which formed an interlacing mass of crystals as much as 17 inches long. In many of these caves residuary masses of oxidized lead and copper ores were found. Most of the caves were caused by the contraction of volume due to oxidation of the ore and by the subsequent settling of the limestone.

He specifically describes a cave due to oxidation subsidence in speaking of the Iron Blossom No. 3 mine:[4]

> A large cave was found in the southern part of the No. 3 workings. It is 250 feet long, 40 to 60 feet wide, and 10 to 20 feet high. It lies about parallel to the ore body and just above it. Its outline in longitudinal section resembles the section of a bowl. At the bottom of the cave is some carbonate ore showing copper stain, and this material is in part stoped. The walls of this cave were coated with snow-white botryoidal masses of calcite and beautiful arborescent growths of the same mineral. In places the calcite was covered by needles of aragonite. This secondary calcite contains no ore minerals. There is little doubt that the cave was produced by the oxidation and shrinkage of the ore body below it.

Shrinkage of a massive pyrite vein, dipping 60°, from a thickness of 25 feet to a residual barite sand compressed down to a body only 3 to 6 feet wide, and proportionally enriched in gold and silver, and the consequent collapse and jumbling of the schist hanging-wall, were described by Stickney[5] in 1915.

Emmons,[6] in his "Principles of Economic Geology" sets forth in a general way the conditions resulting from oxidation:

> *Conditions in the Oxidized Zone.*—The oxidized zone is in the main the zone of solution. . . . Solution generally exceeds precipitation, how-

[3] W. Lindgren, G. F. Loughlin, and V. C. Heikes, "Geology and Ore Deposits of the Tintic Mining District, Utah," U. S. Geol. Surv., Prof. Paper 107, p. 161, 1919.

[4] *Op. cit.*, p. 239.

[5] Stickney, A. W., "The Pyritic Copper Deposits of Kyshtim, Russia," Econ. Geol., vol. 10, 1915.

[6] Emmons, W. H., "The Principles of Economic Geology," p. 139 (1918).

ever, and by solution the mass is reduced and open spaces are enlarged. The increase in the size and volume of the openings renders the downward circulation comparatively free in the zone of oxidation.

Again,[7]

> Oxidized ore is generally spongy and contains numerous cavities due to solution. The iron ores formed by the superficial weathering of ferruginous igneous or sedimentary rocks are almost invariably open-textured, although in some deposits the pore space formed by the removal of valueless material is eliminated by slumping near the surface or by cementation with iron oxide at lower depths. Gossans of sulphide ores contain many openings ranging in size from minute pores to enormous caves. Stalactites, stalagmites, organ pipes, botryoidal masses and reniform bodies are characteristic.

In 1924 H. M. Kingsbury, who was familiar with the Kyshtim district, identified a body of brown sandy gold ore at Bisbee as very similar in appearance to the residual Kyshtim sands. Shortly afterward he observed a body of breccia one to two hundred feet wide and several hundred feet long, made up of jumbled fragments of limestone and jasperoid and closely resembling coarse stope filling except that it was cemented by calcite. This body of breccia is coextensive with and immediately overlies a stope which produced oxidized copper ore, and reaches a height of 100 feet above the top of this ore body. He regarded this breccia as the result of oxidation collapse, caused by the shrinkage of the ore body during oxidation.

In 1925 the writer came to the Bisbee district in order to develop the subject of oxidation subsidence as a guide to ore. Four months were devoted to this study, and it is on the results of that work that this paper is based.

METHOD OF STUDY EMPLOYED AT BISBEE.

The method of study employed was simply an examination of conditions existing above known bodies of oxidized ore. The region selected was that lying southwest and south of the Czar shaft and to the southeast of the original Copper Queen ore body.

[7] *Op. cit.*, p. 143.

This area offered the advantages that it contains large stopes which produced oxidized ore, that the ore bodies came close to the surface and that the workings above the stopes are reasonably accessible. Further, the presence of mine cracks and mine subsidence presented an opportunity to compare the results of mining with those of oxidation, provided some means could be found of distinguishing the two. Since both types of subsidence resulted from essentially the same thing, namely, the weakening of the ground above by removal of material below, it was expected that valuable analogies could be developed in the more obvious mine subsidence for use in the study of oxidation subsidence.

The problem of distinguishing mine subsidence from oxidation subsidence was readily solved. The mine cracks in many instances were seen to carry a thick coating of banded calcite clinging to one or both walls. Where calcite was found on both walls, that on one wall could be fitted exactly to that on the other—the mine crack had merely reopened a calcite-filled fissure. In many cases the calcite could by traced beyond the horizontal limits of the open mine crack into ground unbroken by mining. Further, the calcite clings to the walls of the cracks as tightly at their very tops as it does far below—the present erosional surface has obviously truncated the calcite veins. Finally, in many places underground, areas of jumbled rock, tightly cemented by calcite, were discovered over stopes, and above the limits of mine disturbance. The loose blocks beneath these areas and directly overlying the stopes (in the zone of mine collapse) were found to be coated with calcite of the same type as that cementing the bouldery ground above. It is clear that the jumbled rock formed by oxidation subsidence, and later cemented by calcite, has been loosened up again by mining subsidence. In other words, mining subsidence has repeated in large measure the manifestations of the previous oxidation subsidence, and the two processes have substantially the same effect upon the overlying ground.

All evidences of pre-mine subsidence were mapped in the area studied, without any specific knowledge of the location of the stopes below. Horizontal projections were then made, and the

subsidence maps of the levels above these stopes, and of the surface, were superimposed upon these. Two sets of vertical sections, at right angles to each other, were run through the area.

The conclusions reached are outlined in the following pages. As a preliminary to their discussion, a brief summary is given of those effects of mine subsidence which most closely parallel the oxidation subsidence effects.

MINING SUBSIDENCE.

The Dome of Equilibrium.—The tendency of the unsupported back of any mine opening to assume the shape of a self-supporting dome or arch is well known. Thus the back of an opening long in one dimension, as a drift, tends to form an arch by slabbing or scaling until the form of arch is attained which is self-supporting in the given rock. Similarly, the back of an opening approximating a square or circle in horizontal section tends to assume the shape of a dome by a series of falls of rock, first over

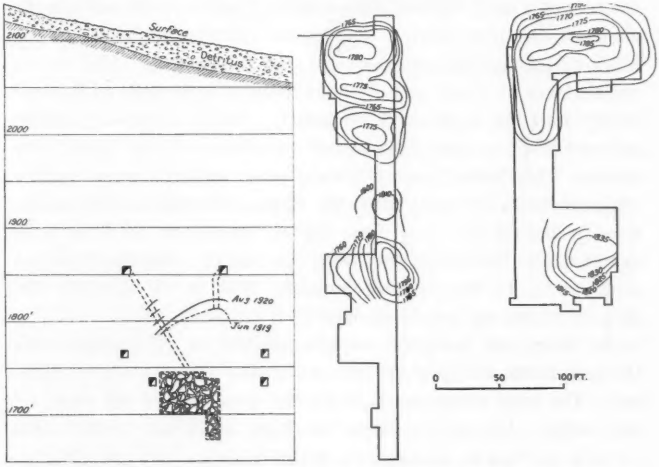


FIG. 1 (left). Doming cracks above filled square-set stope.
FIG. 2 (right). Collapse domes above filled square-set stopes at Ray.

the center of the opening, then successively toward the sides. In homogeneous rock, slabbing or doming cracks are formed successively higher and higher above the opening, and it is by the slabbing off of the shell of rock between the roof of the opening and the doming crack next above it that the dome grows upward. This dome may be called the dome of equilibrium, referring to the undisturbed rock above it, or the collapse dome, referring to the collapsed rock below it. Fig. 1 shows doming cracks formed above a filled square-set stope at Ray, with the dates of formation of two of the cracks. Fig. 2 shows in plan the shape of the domes of equilibrium above two similar stopes in the same mine.

Where the country rock is thin-bedded, the effects closely resemble the experiments of Fayol.[8] The overlying beds fail successively by sagging and fracturing; but the upper limit of the sagging takes the shape of a dome.

Marginal Cracks.—If the effects of mining operations reach the surface, the first manifestations are usually cracks, which, in the case of a large flat ore body, outline roughly on the surface the shape of the stope below. The cracks indicate the failure of the block of ground between the stope and the surface. The cracks are surfaces of shear, and the block within them tends to descend bodily into the excavation beneath it. With square-set-and-fill or cut-and-fill stopes, little actual subsidence of the block may occur. This is the case at Bisbee, where gaping cracks outline with exactness the margins of the stopes, although actual subsidence is limited to a few feet. If no attempt is made to hold permanently the back of the stope, this sheared plug may descend bodily into the stope and completely close it. Frequently the plug is broken up into fragments as it descends.

At Bisbee, the marginal cracks extending to the surface from the peripheries of the stopes are in almost every case nearly vertical. The most pronounced cracks are directly over the edges of the stopes. Where the stopes are high, secondary cracks, also

[8] Fayol, M., "Sur les Mouvements de Terrain Provoqués par l'Exploitation des Mines," *Bull. de la Soc. de l'Industrie Mineral,* II. Série, Tome 14, 1885. (See Fig. 553, "Mining Engineers' Handbook," Ed. by Robert Peele, 1918 Edition.)

vertical, form outside of the marginal cracks proper, but these in no cases descend as low as do the true marginal cracks.

Where a hill adjoins the subsided area, there is a decided tendency for the marginal cracks to bulge outward (in plan) toward the hill. If this flaring of the true marginal crack does not occur, and the crack clings to the periphery of the stope, secondary marginal cracks, outside of the true marginal cracks, often form on the side of the hill. In either case, the cracks are vertical, and not inclined outward from the stope, but the disturbance has a

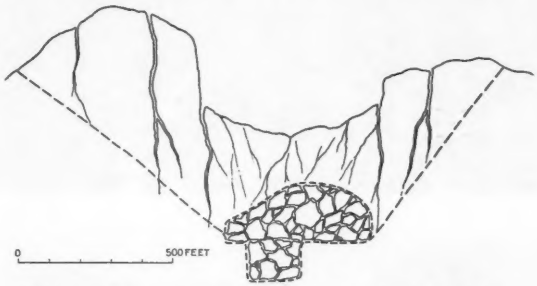


FIG. 3. Primary and secondary mine marginal cracks.

sort of "draw" (Fig. 3) in that the bottoms of the primary and secondary marginal cracks may be connected by a fairly straight line. This line makes an angle with the horizontal of between 45° and 60°, depending upon the nature of the ground and possibly upon the method of mining.

There is some evidence at Bisbee that the marginal cracks and the dome of equilibrium tend to assume an attitude between the vertical and a line drawn normal to the beds, but the beds in the area studied are so flat-lying that no proof of this could be obtained. The generalization appears to hold for other districts.

With the block-caving system of mining, marginal cracks are likewise developed, but as in this method there is no attempt to support the back, once drawing has started, and every effort is made to cave the ground all the way to the surface as rapidly as possible, the result is that the doming effects reach the surface.

This is shown in the accompanying photographs (Fig. 4) of the surface over a caved block at Ray. The first subsidence effect to reach the surface is a small hole directly over the center of the

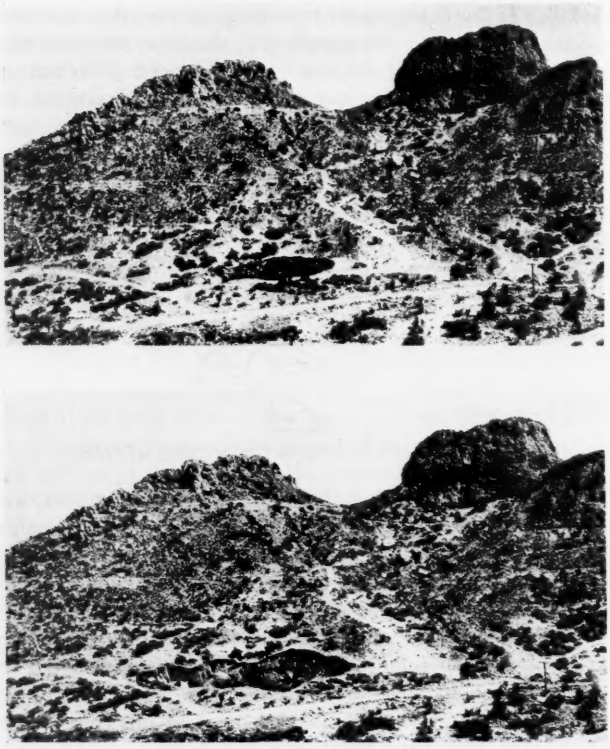


FIG. 4, *A–B*. Successive stages of caving to surface. See also Fig. 4, *C–D*.

stope. This rapidly increases in size and very shortly the marginal cracks appear, outlining the horizontal periphery of the

stope upon the surface. The caved area grows from the central hole toward the marginal cracks until all the area within the cracks is engulfed.

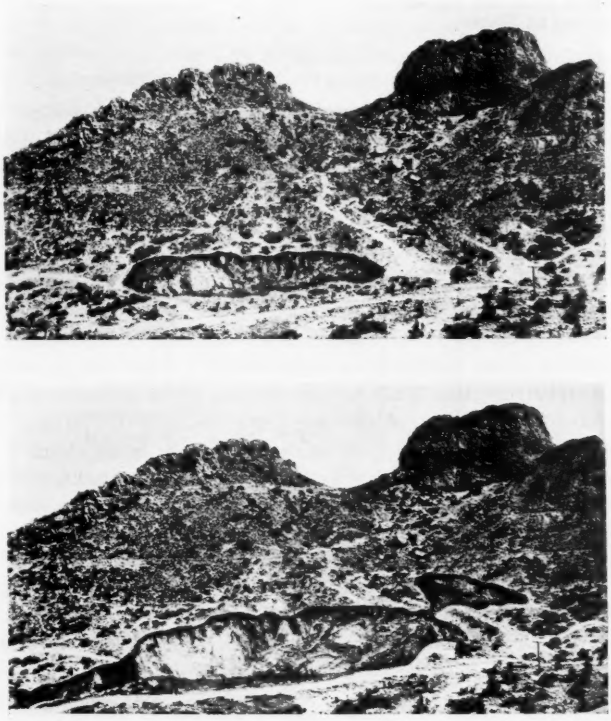


FIG. 4, *C–D*. Successive stages of caving to surface. See also Fig. 4, *A–B*.

Subsidence due to coal mining [9] parallels in general the effects described above, especially the room and pillar method, involving

[9] Report of Subcommittee on Coal Mining to Committee on Ground Movement and Subsidence, *Trans. Am. Inst. Min. and Met. Eng.*, No. 1546–F, Feb., 1926.

the removal of ground at a relatively slow rate. The long-wall method, whereby a flat seam is removed with great rapidity, seems to give a pronounced draw to the marginal cracks, which flare outward from the periphery of the mined area in a manner not observed at Bisbee.

GENERAL FEATURES OF OXIDATION SUBSIDENCE.

The ore bodies in the area studied at Bisbee are replacements in flat-dipping limestone beds, and are therefore in general flatly tabular in shape, their length and breadth being greater than their height. The primary sulphides were pyrite, chalcopyrite and some bornite. The extent of the replacement, as indicated by primary ore elsewhere in the district, varied from the scattering of sulphide grains and blebs through the country rock to a complete replacement of the limestone.

The oxidation of the ore bodies was accompanied by two distinct but closely related types of subsidence. Where the ore body was relatively close to the surface (that is, where the ratio, width of ore body to vertical distance from ore body to surface, is large), the ground above the oxidized ore body tends to subside as a plug bodily into the weakened block. Shear cracks, rising steeply from the periphery of the ore body to the surface, determine the horizontal limits of the plug. The actual downward movement of the plug may be slight.

The second type of subsidence is by doming, effected by the progressive breaking away of the fractured, loosened material above a weakened block by spalling and arching. This material is jumbled by its downward movement. The upper surface of the jumbled ground assumes the shape of a dome, which grows upward by successive slabbing along doming cracks parallel to the dome itself. The proportions of the dome depend upon the strength and structure of the rock overlying the ore body. Other things being equal, the more competent the rock above to act as a beam, the flatter the dome.

The dome is apparently developed to some extent whether or not the marginal cracks occur. Doming appears to be inevitable

so long as the plug does not actually descend and come to rest upon the top of the oxidized ground. Where the effects of subsidence are not transmitted to the surface, the subsidence appears to be limited to the block of ground beneath the dome of equilibrium, and the ground above is competent to support itself, despite the opening below, by virtue of the structural stability of the dome. No data are at hand, however, to prove that there are no marginal cracks which die out before reaching the surface, as might be the case with very deep ore bodies.

Where the effects of subsidence are transmitted to the surface

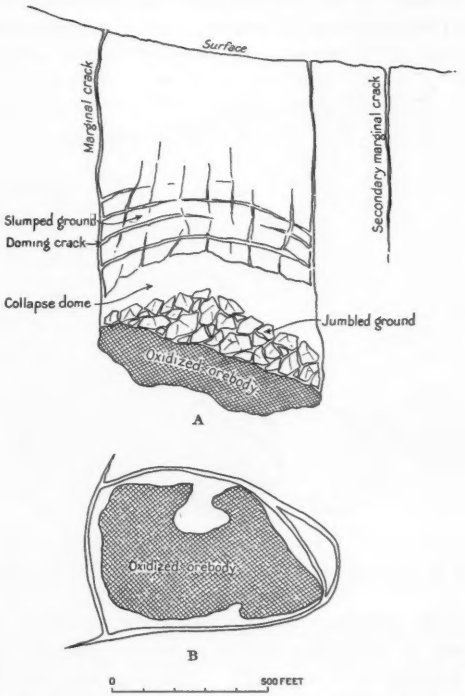


FIG. 5. Subsidence features in massive limestone, near surface.

through marginal cracks, the doming apparently proceeds upward to a greater distance above the ore body than where no marginal cracks occur. This is to be expected, since where marginal cracks occur the footings of the dome have little or no support, and slabbing upward is facilitated by the presence of free faces to which to break. Tensile strength is no longer an important factor in maintaining the slabs in position.

Secondary marginal cracks are cracks parallel to the true marginal cracks and outside of them. Secondary cracks, as seen in plan, may leave and return to the marginal cracks or may remain outside of them. Their dips appear to be identical with those of associated marginal cracks, namely, vertical or nearly so. Some however appear to join adjacent marginal cracks in depth.

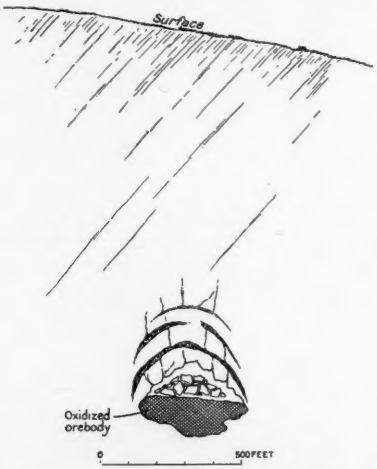


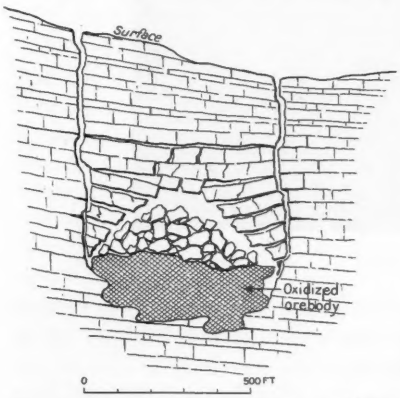
FIG. 6. Subsidence features in massive limestone at depth.

Like those resulting from mining these secondary marginal cracks seem to form most readily where the primary crack runs along a contour of a steep hill. This suggests that allowance must be made in estimating the area of the underlying ore from

the surface effects of oxidation subsidence where the effects are manifest on a steep slope.

It has been found that the thickness or thinness of the beds has an important effect on the results. Where the limestone is massive or thick-bedded (Fig. 5) the marginal cracks are well-defined and persistent, with smooth walls. The doming cracks are strong and continuous and the rock above the top of the ore and below the collapse dome is broken into large boulders, which have suffered rotation. Above this "jumbled" ground (Fig. 9) is the "slumped" ground, where the rock is full of minor cracks, most of which carry banded calcite. The cracks are steeply dipping and roughly perpendicular to each other in strike, thus dividing the ground up into irregular prisms. These prisms are cut into blocks by minor doming cracks or bedding planes, whose opening accompanies the upward climb of the dome of collapse.

Where the limestone is thin-bedded (Fig. 7) the marginal



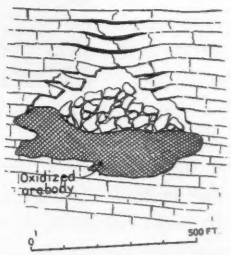


FIG. 7 (left). Subsidence features in thin-bedded limestone, near surface.
FIG. 8 (right). Subsidence features in thin-bedded limestone at depth.

cracks are individually less continuous and are more truly zones of fracturing. The doming cracks are likewise more irregular. The beds are pulled apart to form slump caves in many irregularly

spaced places. The collapse dome itself is ill-defined, but the region of slumping as a whole appears to extend higher above the ore, other things being equal, than in massive beds. The thin beds have been separated by sagging for a considerable distance above the ore body, as clearly indicated by interbed fine-banded calcite. In places mud, sand and even conglomeratic material has been deposited between the beds. True doming cracks, convex

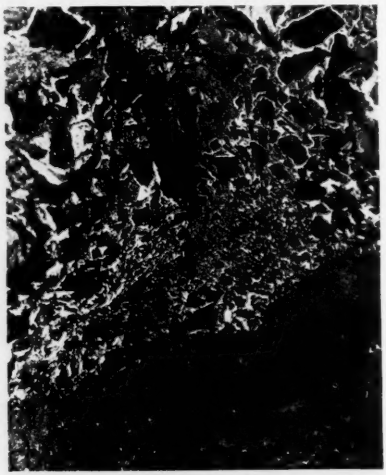


FIG. 9. "Jumbled ground." (Photo by H. M. Kingsbury.)

upward, may be lacking, and their places taken entirely by these sag cracks. The greatest sag is directly over the apex of the oxidized ore body, the amount of sag decreasing in all directions toward the margins. It should be remembered in this connection that the thickness or thinness of the beds is relative, and with a very large ore body even thick-bedded limestone may behave in this manner, giving sagging cracks instead of doming cracks. As seen in Fig. 7 however, an irregular dome does occur even with thin-bedded limestone, formed by the ends of the sagging beds breaking off in the manner shown.

THE INFLUENCE OF PRE-OXIDATION FRACTURES.

It is to be expected that where stresses are set up in country above a weakened block of ground, they will find expression along any preëxisting lines of weakness which are at all conformable in attitude and position with the direction of the stresses. As a matter of fact, in the area studied, perhaps 75 per cent. of the breaks mapped run parallel in strike to the three main faults which roughly bound the area, the Czar, Ella and Dividend faults. Such results are certainly to be expected, and should in no way interfere with proper interpretation, for although the oxidation breaks follow fissures established previous to oxidation, they do so only in the country above the ore. That this is so, is proved by the occurrence of banded calcite, indicating reopening of the fissure, only in those parts of the old breaks which traverse the country above the ore.

FEATURES CONFUSED WITH OXIDATION SUBSIDENCE.

It is obvious from the preceeding description of the features due to oxidation subsidence that there is danger of confusion with features resulting from other causes. Thus "weathering" or solution fissures may closely simulate openings due to the withdrawal of support below. Solution of a particular bed, especially where the bed has been warped, gives rise to an opening greatly resembling a doming crack. An ordinary solution cave sometimes attains such size that the roof collapses and "domes" itself. This gives a dome above a mass of rubble in no way distinguishable by itself from a collapse dome caused by oxidation of an underlying ore body. In general the following criteria hold for distinguishing open solution caves from open collapse caves (see Fig. 10):

A. Solution Caves (Fig. 10, *A*).

1. Characteristically pitted and rounded walls, floor and roof.
2. Most of the limestone is removed from the cave, but the latter may be filled with calcite as stalactites and stalagmites, introduced since the formation of the cave.

3. A solution cave usually occurs along a particular soluble bed, seldom crosses the boundaries of this bed, and is commonly associated with a solution fissure.

B. Oxidation Collapse Caves (Fig. 10, *B*).

1. The roof is jagged due to falls of rock.
2. Most of the limestone remains in the cave as fragments, often cemented and partly covered by calcite.
3. The cave is not limited to a particular bed.

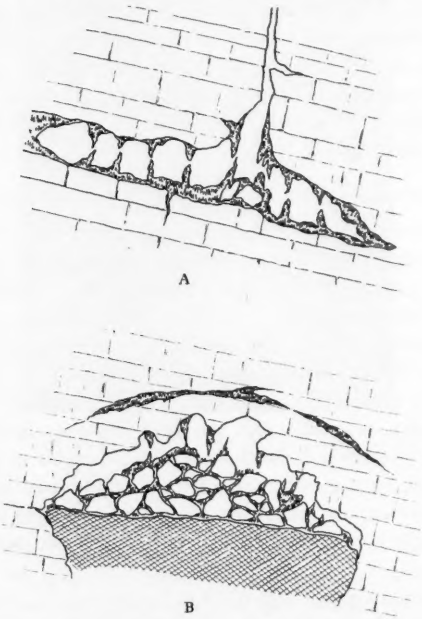


FIG. 10. Solution and collapse caves.

Solution of the limestone has in places been greatly stimulated in the vicinity of oxidized ore bodies. The rock has been intensely eaten along minute fissures, forming a kind of solution

breccia superficially resembling collapse caused by the withdrawal of support below. (See Fig. 11.) Open caves are occasionally formed adjacent to oxidized ore bodies by solution alone. While

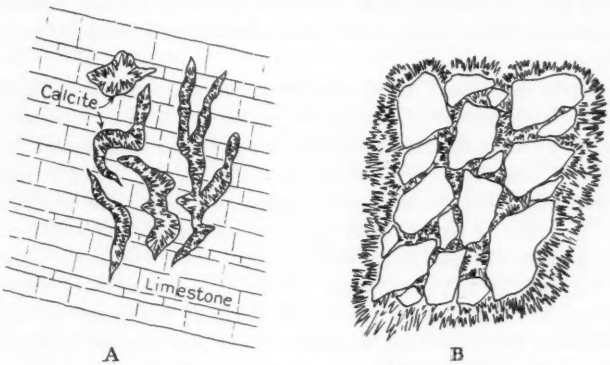


FIG. 11. Solution breccia (*A*), and collapse breccia (*B*).

these caves are usually below the ore body, they may be in almost any position with respect to it. They will seldom be confused with oxidation collapse caves.

THE FIELD APPEARANCE OF OXIDATION SUBSIDENCE AT BISBEE.

A description follows of the characteristics of oxidation subsidence in the ground above the oxidized ore body, from the surface down to the top of the ore body.

Certain small ore bodies at Bisbee, occurring at considerable depth below the surface, show no surface effects of oxidation, but the majority of them do, in the area studied, where detritus does not mantle the overlying surface. The effects upon the surface are obscured, compared with their appearance underground, for several reasons. Ordinary processes of surface weathering tend to obliterate small fissures. Large fissures are often filled by washed-in detrital matter or by the crumbling of the walls. The oxidation fissures of the area studied are typically filled with banded calcite. This material, weathering more rapidly than the

enclosing limestone, produces a trough or ditch which makes an efficient trap for the detritus constantly transported by rain-water and gravity down the sides of the hills. The result is that oxidation fissures are difficult to recognize and map for any distance unless they have been reopened and accentuated by mining operations.

Upon the surface, then, whether or not the oxidized ore body below has been mined, the outline of the ore body is often projected by marginal cracks characteristically filled with banded calcite. These cracks are vertical or nearly so, and either located without reference to any faults nearby, and solely with reference to a margin of the ore body below, or are reopened portions of faults which happen to parallel a margin of the ore body. Also "regional" cracks may occur, which have reference to major groups of ore bodies but not to individuals of the group, so that, where an area of oxidation subsidence has been mapped by means of the marginal cracks, we cannot be sure that such an area is continuously ore-bearing.

Where the ore bodies underlie the surface at shallow depth, not only the marginal cracks, but also the zone of slumping may reach the surface, and an area will be mapped which is traversed by innumerable minor fissures with no dominant orientation, but rather sharply cut off from the surrounding country by the marginal cracks. With ore at still shallower depths, the collapsed ground may be seen at the surface, the rotated fragments usually being well-cemented, so that the result is a hard breccia easily recognized.

Subsidence may be indicated on the surface by topographic depressions. These are of two kinds, one caused by the bodily descent of the plug of ground bounded by marginal cracks, and the other caused by the sagging of the beds above an oxidized ore body—a synclinal trough. The former is characteristic of massive rock, the latter of moderately thick-bedded to thin-bedded limestone.

Underground the effects of subsidence are more readily visible, but the limited opportunities for mapping that are afforded by

mine workings often counteract this advantage. Upon entering a region of slumped ground, the first thing noticed is the increased fracturing of the ground, which is cut up into blocks by minor fissures, most of which are steeply dipping. They may be open, but most of them are filled with banded calcite. Where mining has occurred below, the cracks have generally been reopened or widened, but the calcite still clinging to their walls shows their pre-mine origin. The contact between the slumped ground and that unaffected is often marked by the marginal crack, vertical or nearly so, with smooth walls bearing thick-banded calcite. Movement along the crack is sometimes shown by slickensiding. Mining operations nearly always reopen such cracks, and mud, sand, gravel, etc. have often been washed into them, although in many cases this material also is pre-mine. Where the limestone is thin-bedded, the separation of the beds due to sag is very striking, and banded calcite usually fills the gaps. In massive ground, doming cracks, gently convex upward, show that the workings are not far above the dome of collapse; the wider the doming crack, the nearer it lies to the dome. These doming cracks, in virgin ground, are often completely filled with calcite. In the cracks which were never completely filled, the calcite rests in great mammilary masses upon the floor, giving a very characteristic appearance.

Upon descending further toward the top of the ore body, the collapse dome may be seen. Its roof resembles that of a doming crack, but beneath the roof is the jumbled ground which directly overlies the ore body. This jumbled ground (Fig. 9) furnishes the most striking of the oxidation subsidence effects, and once seen is not likely to be confused with other breccia types. Here the structure of the country has entirely disappeared. The ground has been broken into fragments which have suffered pronounced movement and rotation. Calcite may have completely cemented these boulders so that the story of collapse must be read upon a solid wall, or the fragments may rest upon each other loosely, ready to tumble into any opening below. Whether or not the collapsed ground has been knit again by calcite into strong

rock which stands well in mine workings, the appearance of the whole is strikingly indicative of the removal of support below.

EXAMPLES OF OXIDATION SUBSIDENCE.

The Surface.—(Fig. 12.) The southwest margin of the whole

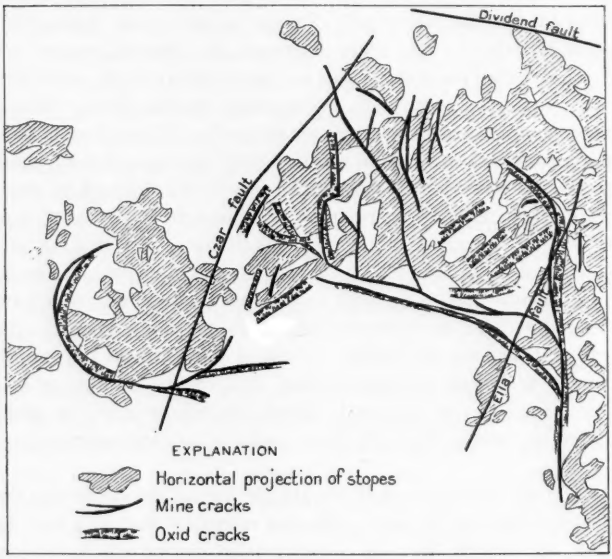


FIG. 12. Plan of surface.

group of ore bodies in this area is defined on the surface by a strong zone of cracks trending northwest-southeast. Roughly perpendicular to this zone of "regional" cracks is a group of minor marginal cracks which closely follow the eastern or western margins of individual ore bodies. These north-south cracks are very numerous in the area, while east-west cracks are rare, except for the above-mentioned regional cracks. There are two reasons for this. First, the individual ore bodies of the area are

replacements of favorable beds along their intersections with fractures sympathetic with the Czar fault, which strikes about N. 30° E. The longest dimensions of the ore bodies have also this strike,

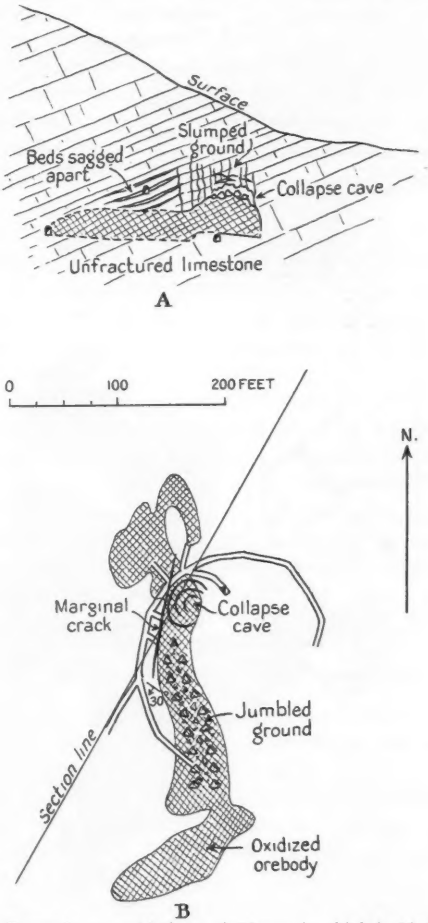


FIG. 13. Example of oxidation subsidence in thick-bedded limestone.

and the ore bodies are often pointed at their northeast and southwest ends. The longest, most important marginal cracks would therefore strike roughly north-south. Second, as the pre-oxida-

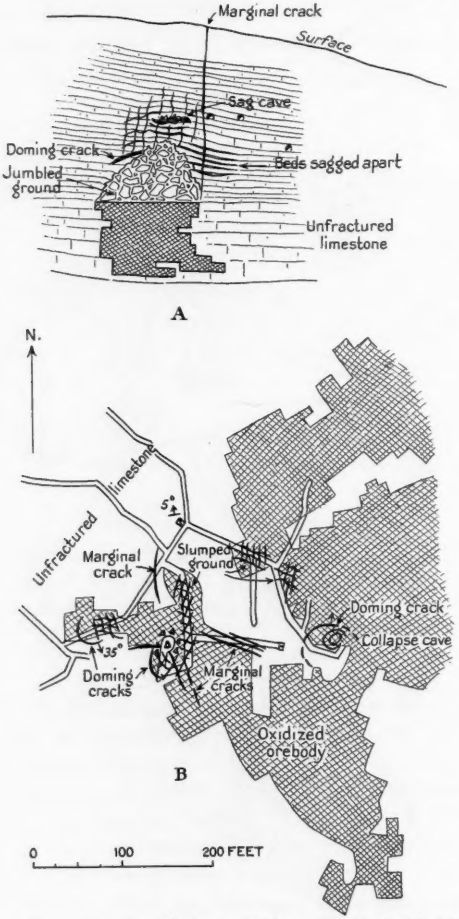


FIG. 14. Example of oxidation subsidence in thin-bedded limestone.

tion fractures of the area are in most cases sympathetic with the Czar fault, stresses set up by oxidation subsidence naturally followed these fractures more readily than along directions transverse to them.

Fifteen separate pre-mine cracks were mapped which were coincident with the projections of stope margins upon the surface. Those not obviously related to stope margins are either regional cracks, related to the whole group of ore bodies but not to individuals, or cracks which run within the horizontal projections of the ore bodies but are parallel to the edges of their thickest portions.

Subsidence in Thick-bedded Limestone.—Fig. 13 shows subsidence effects connected with an oxidized ore body in thick-bedded limestone. A collapse cave surmounts the thickest part of the ore body and beneath the cave lies the jumbled ground. Other manifestations shown are the sagging apart of the beds and a well-defined marginal crack. The sagging apart of the beds is of local occurrence and immediately over one edge of the ore body.

Subsidence in Thin-bedded Limestone.—Fig. 14 shows subsidence effects mapped above extensive ore bodies in thin-bedded limestone. While collapse caves and doming cracks exist immediately above the ore bodies, sag cracks or sag caves occur fully 90 feet above the top of the ore, illustrating the tendency of the sagging effects to climb high in thin-bedded limestone. The close association of the marginal cracks with the ore boundaries is well shown in Fig. 14.

SUMMARY OF RESULTS OF MAPPING SUBSIDED GROUND.

Nineteen areas were mapped as showing oxidation subsidence which were found to be directly above known ore bodies and clearly outlining them.

In two areas above known ore bodies oxidation subsidence was not detected. In one case the limestone is altered to kaolinic material, making heavy ground in which fractures tend to seal and become lost. In the other case close timbering obscured the evidence. In no case was there failure to recognize subsidence

above a known ore body where the workings were untimbered, and the structure was not obscured by such alteration as that described above.

Four areas were mapped as showing oxidation subsidence which are not over known ore. In three of these cases lessees told the writer that ore underlay or had underlain the areas. The country below is now inaccessible, so that this could not be verified. The other case was close to the margin of a stope below, and here apparently the subsidence jumped across barren ground between two ore-bearing areas.

APPLICATION OF OXIDATION SUBSIDENCE TO UNDEVELOPED GROUND.

Once the presence of oxidation subsidence has been established, certain conclusions can be drawn from the evidence which serve to point out in a rough way the location of the ore bodies.

The marginal cracks enclose the ore-bearing area and point downward vertically to the margins of the ore body. Marginal cracks alone tell little as to the depth below the point of observation at which the ore body lies. They extend in known instances 300 feet above an ore body 200 by 200 feet in areal extent, and at least 700 feet as regional cracks connected with a great group of ore bodies, and in each of these instances they formerly went higher, since their tops have been removed by erosion. Some judgment may be used here. If the area enclosed is quite small, the ore body probably does not lie far below, since with small oxidized ore bodies at great depth the effects of subsidence would not be transmitted to the surface and no marginal cracks would appear. The possibility of depth increases with the size of the area enclosed by the marginal cracks.

Doming cracks likewise vary in meaning with their size. Small, acute domes indicate small ore bodies not far below. Other things being equal, the larger the ore body in areal extent the larger the dome and the higher it extends above the ore body. The ore body lies beneath the apex of the dome, so that where a doming crack is mapped on a mine level, its horizontal trace is ob-

tained, and this is circular and concentric with the ore body; that is, the center of this circle is vertically above the center of the ore body.

Sagging of the beds in formations of alternating thick and thin beds indicates an ore body at shallow depth, since such sagging would not be transmitted through the massive, competent beds for any great distance above the ore body. Where all the limestone is thin-bedded, sagging may occur at much greater distances above the ore. Slumping, indicated through the division of the ground into blocks by open or formerly open fissures, means comparative closeness to the top of the ore body, and the distance varies inversely with the degree of slump. Collapsed or jumbled ground indicates nearness to the top of the ore and below the dome of collapse. The area of slumping or collapse mapped will usually give the minimum area of the ore body below, since the subsidence seldom extends out beyond the margins of the ore-block; and inasmuch as the jumbled area is bounded above by a dome, the limits of the ore may be outside those of the jumbled area mapped.

As a rough rule, which may be applicable only in the area here studied, it may be noted that the ground at vertical distance greater than 100 feet above ore bodies less than 50 x 50 feet in area is unaffected by slumping. Marginal cracks however may indicate the ore, provided the body lies at shallow depth below the surface.

No rule was worked out regarding the relation of height reached by collapse or slumping to thickness of ore body (the dimensions of the ore body being considered as length, breadth and thickness). The following considerations are offered:

1. With a very thin, interbed ore body, sagging of the beds, as shown in Fig. 15, occurs for a short distance above the ore, the amount of sag decreasing upward and finally dying out.

2. A vertical pipe or vertical tabular ore body has a structurally strong roof, so that, for a given volume of ore, the effects of subsidence (the doming and slumping) will be at a minimum if the ore body has either of these shapes. Furthermore, for a given

volume of ore in a given rock, there is a shape of ore body to give maximum slumping effects. Stated in another way, of two ore bodies having equal horizontal areas of identical outline, but having different thicknesses, and therefore different volumes, the doming and slumping go higher over the thicker ore body, with one limitation. The theoretical reasons for this follow.

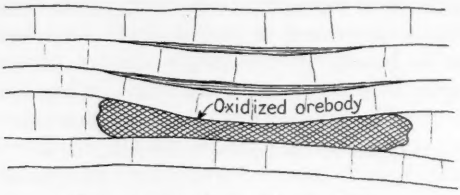


FIG. 15. Sag above thin ore body.

3. The doming above a cavity tends to extend upward until that height is reached at which the dome is competent to carry the overlying load of rock; so that, were the spalled fragments which drop off from below the dome removed, the two ore bodies under consideration would have domes of the same height. We can consider the rock above the cavity as a beam, and this beam must, of course, have a certain thickness not to fail. If it should fail, the rock between the cavity and the surface would subside into the cavity. But if the beam should be too thick and strong to fail, its under side would spall off until a dome were produced. At a given depth below the surface, in a given rock, over a cavity of a given size, there is a certain height which the dome must reach to attain stability, just as structural arches must have a given spring in a given material.

It is probable that this theoretical height of the dome of equilibrium is seldom reached. The material from beneath the dome will, if the dome rise high enough, completely fill the original cavity as well as most of the dome itself, due to the "swell" of broken ground. This support will tend to buttress the dome and give it stability at heights under the theoretical height for the given span. In such a case, the theorem that the thicker the ore body the higher the dome follows very simply (Fig. 16).

In Fig. 16, V = the volume of the original cavity, taken as completely emptied.
D = the volume of the dome.

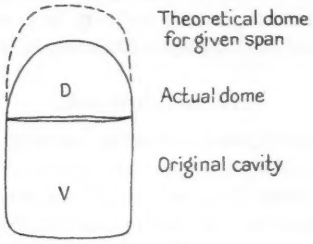


FIG. 16.

Let the increase in volume due to spalling = 40 per cent. Then, completely to fill both dome and original cavity,

$$D + .4D = V + D$$
$$.4D = V \text{ or } D = 2.5V$$

In other words, D varies directly as V, and the thicker the ore body, the higher the dome, horizontal areas being equal. But the original cavity is never a complete cavity, so that the constant 2.5 connecting D and V is, of course, incorrect. For example, if 40 per cent. of the original volume of the ore was removed by solution, we have

$$D + .4D = .4V + D$$
$$.4D = .4V \text{ and } D = V$$

The constant is therefore one, so that the volume of the dome equals that of the ore body.

In applying the ideas of oxidation subsidence to undeveloped ground, it must be borne in mind that bodies of massive pyrite undergoing oxidation have a tendency to shrink and to cause the failure of the overlying ground just as do the copper ore bodies. There exists every gradation between ore bodies consisting chiefly of chalcopyrite and bornite, with comparatively little pyrite, and

bodies of pyrite containing practically no copper. The study of the oxidation subsidence features by themselves affords no means of ascertaining the copper content of the underlying oxides. A knowledge of the habit of the nearby ground, together with any other lines of evidence possible to bring in is necessary for the final interpretation of oxidation subsidence in terms of ore.

ACKNOWLEDGMENTS.

Grateful acknowledgment is made to Augustus Locke and F. L. Ransome, for criticism and other aid, and to the Copper Queen Branch, Phelps Dodge Corporation, and the Ray Mines, Nevada Consolidated Copper Co., for permission to publish data relating to their mines.

PACHUCA,
MEXICO.

OIL AND GAS POSSIBILITIES OF VIRGINIA.

ALBERT W. GILES.

INTRODUCTION.

THE prospect of obtaining commercial quantities either of oil or gas within Virginia is regarded by geologists as distinctly unfavorable. This conclusion at first thought may seem surprising, for the State possesses a remarkable stratigraphic sequence. Archeozoic and Proterozoic rocks underlie one fourth of the area of the State, and all of the later systems are represented with the exception of the Permian and Jurassic. The Paleozoic group is remarkably complete and the Tertiary underlies nearly one fourth of Virginia. All of the major geologic provinces of eastern United States occur in the State (Fig. 1). They are as follows, named from east to west: Coastal Plain, Fall Belt, Piedmont Plateau, Blue Ridge, Great Valley, Newer Appalachians or Alleghany Ridges, Appalachian Plateau.

The geography, stratigraphy and structure of each of these provinces will be considered together with their possibilities for the occurrence of oil or gas in commercial quantities.

THE COASTAL PLAIN.

Geography.—The Coastal Plain or Tide-water Virginia comprises about 10,500 square miles, of which about 2,365 square miles are covered by Chesapeake Bay and the many estuaries that mark the lower courses of its tributary streams. Its length, from the North Carolina line to Potomac River at Alexandria, is 185 miles, and its maximum width in the latitude of Fredericksburg is about 115 miles. Its shore line is nearly 2,000 miles long.

The average elevation of the Virginia Coastal Plain is slightly more than 100 feet above tide. The highest parts are found near its western margin in the vicinity of Washington with eleva-

FIG. 1. Physiographic Provinces of Virginia.

tions of more than 400 feet above sea level but the average elevation of its western margin is only about 300 feet. On the west the easterly slope of the surface of the Coastal Plain is 10 to 15 feet to the mile, but it gradually declines to less than one foot per mile in the eastern part of the State. On either side of Chesapeake Bay there are wide areas of monotonously flat land, only a few feet above water level.

Stratigraphy.—The rocks of the Coastal Plain range in age from Comanchean to Recent (1).[1] They consist essentially of gravels, sands, clays, marls, glauconite and diatomaceous earth, for the most part uncemented. They are lenticular, and one rock type is likely to grade horizontally into another type. The rocks are generally light in color and weather to bright hues. Dark sands and clays charged with organic matter are uncommon and of limited extent, although lignite is present locally in small quantities. Peat and muck beds occur in the Recent series uncovered or with but shallow covering. The sediments rest upon an old erosion surface of crystalline rocks, the extension of the Piedmont eastward to an unknown distance. Tables previously published[2] present the essential stratigraphic features of the Virginia Coastal Plain.

The maximum thickness of the Coastal Plain sediments is unknown. At Fort Munroe a deep well penetrated the crystallines at a depth of 2,242 feet. On the Eastern shore east of Chesapeake Bay, the thickness is probably greater, and it may be greater west of Chesapeake Bay due to irregularities in the crystalline floor.

Structure.—The floor of crystalline rocks upon which the Coastal Plain sediments rest dips gently seaward. The beds just above the crystalline floor have an average eastward dip of about 30 feet to the mile, but the dip decreases gradually upward stratigraphically so that the younger Coastal Plain sediments dip 5 feet or less to the mile. Dips as high as 20° to 40° have been noted in some of the formations, but such dips are local. The region

[1] Numbers in parentheses refer to references in the bibliography.

[2] Va. Geol. Surv. Bull. IV., p. 60; Bull. V., p. 29.

has been repeatedly uplifted and depressed with consequent migrations of the strand line westward toward the Fall Belt alternating with eastward retreats across the continental shelf. As a result younger formations characteristically overlap the eroded and beveled surfaces of the underlying formations.

Faulting is rare in the Coastal Plain sediments and is often difficult to distinguish when present owing to the unconsolidated nature of the beds. The diastrophic movements affecting the Coastal Plain have been so gentle that faulting would not be expected. Doming and anticlinal folding are likewise not characteristic of the Coastal Plain sediments and when flexures are present they possess small dimensions laterally and vertically (Fig. 2).[3]

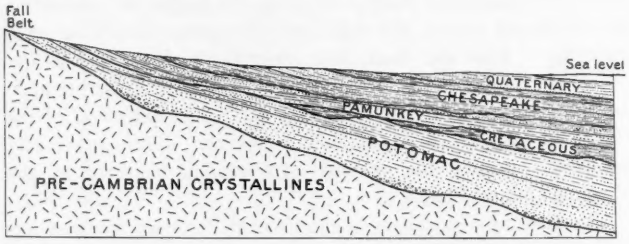


FIG. 2. Geologic section across Virginia Coastal Plain illustrating stratigraphic and structural conditions. Length of section about 70 miles. (Adapted from Bull. V., Va. Geol. Surv.)

Oil and Gas Possibilities.—The possibility of obtaining either oil or gas in commercial quantities from any of the Virginia Coastal Plain formations is far from promising. Numerous deep wells, more than 750, have been driven to obtain supplies of artesian water (2). Most of these wells were so located or are so shallow as to penetrate only the Quaternary and Chesapeake formations. They yield large quantities of water but show no indications of oil and only locally yield gas in small quantities.

[3] The physiographic map and cross section drawings illustrating this paper have been executed by Mr. H. S. Selden of the United States Geological Survey, a master of cartographic delineation.

The wells that penetrate the Pamunkey, Cretaceous and Potomac formations have likewise failed to reveal either oil or significant quantities of gas.

In Telfair County, Georgia, a seep of petroleum having its origin in Eocene or Cretaceous rocks was reported in 1919 (3). The Cretaceous of Louisiana and Texas is oil-bearing. The Cretaceous in Virginia is everywhere buried beneath later formations. In the Virginia Coastal Plain little is known concerning its structure and stratigraphy but it is probably chiefly of stream origin and hence irregular in distribution beneath the later formations. Prospecting by diamond drilling would be uncertain and expensive with slight possibility for profitable returns.

Shallow water wells in Matthews County on Chesapeake Bay yield small quantities of gas which locally may be sufficient for house heating and illumination. The gas originates in Quaternary strata and either represents the decomposition of buried peat accumulations or has its origin in shell beds. The occurrence has attracted considerable local interest but has little to commend it commercially.

A number of explanations to account for the probable absence of commercial quantities of oil and gas in the Virginia Coastal Plain have been offered. It has been suggested that the formations are too thin for the accumulation of large quantities of oil or gas. This suggestion does not seem well founded for the individual thicknesses of the formations are in almost all cases more than 100 feet with an aggregate thickness of all formations in the eastern part of the Coastal Plain of more than 1,000 feet and probably locally more than 2,000 feet.

The porosity of the rocks in parts of every formation is such as to permit the accumulation of either oil or gas, but trap structures are generally lacking. However, the primary reason for the absence of oil and gas probably resides in the insufficient quantities of organic material in the strata to supply the hydrocarbons composing oil and gas, rather than in the infrequent trap structures.

THE PIEDMONT PLATEAU.

Geography.—The Piedmont Plateau occupies the central part of Virginia. It has a width of 40 miles on Potomac River, but broadens southward to a width of nearly 165 miles on the North Carolina line. Its north-south length in Virginia is nearly 200 miles. The total area of the Virginia Piedmont is about 15,500 square miles.

The altitude of the Piedmont surface on the west is between 1,000 and 1,200 feet, and on the east between 250 and 400 feet, resulting in a gentle eastward slope of 5 to 7 feet per mile. The region is maturely dissected, its rugged character increasing westward with increase in altitude.

Stratigraphy.—Granite, gneiss, and schist chiefly of Archean and Proterozoic age underlie the greater part of the Virginia Piedmont. In addition to these there are a number of rock types of different ages developed in considerable areas of the region. A long narrow strip of early Cambrian schists and arkoses extends nearly across the State east of the Blue Ridge. There are several areas with northeast-southwest trend underlain by slates of late Ordovician age, and there are a number of small areas of post-Cincinnatian granites (4). Triassic red beds are found in nearly a dozen areas with characteristic northeast-southwest trend. These are probably the youngest rocks in the Piedmont if the surficial, unconsolidated cover of residual and alluvial material be neglected.

Structure.—The structure of the Piedmont rocks is intricate and difficult to decipher because of the thick mantle of decayed rock. Over much of the region reliance has to be placed on the character of the soil as to the type of rock beneath the surface with little revelation regarding its structure. Igneous structures of intrusive types are characteristic and the foliation and schistosity of the metamorphic rocks are almost universally steeply inclined southeastward at angles of 45° or more. The lower Cambrian rocks are basal parts of closed folds overturned toward the west and truncated by erosion. The Triassic rocks lie in downfolded and downfaulted troughs with depths of several

hundred feet, the strata showing uniclinal structure with prevailing northwestward dips at high angles probably repeatedly interrupted by normal faults. The recognition of these faults is extremely difficult, but the problem has been successfully attacked in Maryland by Miss Jonas of the U. S. Geological Survey.

Oil and Gas Possibilities.—A number of deep wells have been drilled in the Piedmont with the hope of finding oil or gas. Some wells have been sunk in granite and in other places in gneiss or in schist, the financing sometimes being arranged among the local residents. Such efforts can only result in failure. There is no possibility of finding either oil or gas in these ancient crystalline rocks.

It has been suggested that the Triassic rocks might yield oil or gas, but possibilities in these areas are but little more promising than in the crystalline horizons. A deep well was drilled near Orange a few years ago in the Triassic and other unsuccessful attempts have been made. Red beds are not ordinarily oil and gas producing due to the lack of organic matter, and when oil or gas is found in red beds the source of the hydrocarbons is to be looked for in associated beds of marine strata containing organic matter. Such strata are not known in the Triassic. The Virginia Triassic rocks have been so deformed that even small accumulations of oil or gas if originally present would likely have escaped.

Several Triassic basins west of Richmond carry coal in commercial quantities (5). Oil pools are sometimes found associated with strata that contain coals. In such places the percentage of fixed carbon that the coals contain is indicative of the likelihood of the strata containing oil or gas. Experience has demonstrated that if the fixed carbon content of the coal is over 60 per cent. neither oil nor gas will be found, if between 55 and 60 per cent. some light oils may be present with considerable gas, if the fixed carbon content is between 50 and 55 per cent. oils of medium gravity and with little gas may be found. Of 39 analyses of coal from the Richmond Basin, 29 show a fixed carbon content of over 60 per cent. and 12 with the fixed carbon content rang-

ing between 55 and 60. Unfortunately the analyses are rather old but they indicate that the fixed carbon content of the coals is too high to expect commercial accumulations of oil or gas. If they were originally present the deformation of the beds would

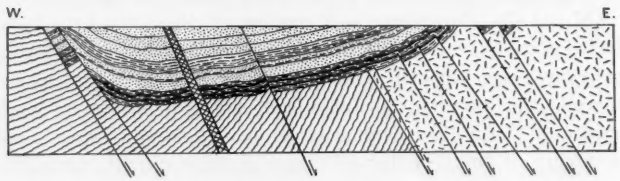


FIG. 3. Generalized geologic section across the Richmond Triassic basin, eastern Piedmont. The Triassic shales and sandstones lie on granite (dashed) to the east, and on gneiss (crenulated) to the west. (Slightly modified after Woodworth, U. S. G. S.)

likely have prevented the retention of oil or gas if formed previous to the time of deformation and would have facilitated their escape if formed subsequently (Fig. 3).

THE FALL BELT.

The Coastal Plain is separated from the Piedmont Plateau by a belt of country ranging from a fraction of a mile to 12 miles or more in width, in which there is a mingling of features characteristic of the two provinces—Piedmont features in the valleys and Coastal Plain features on the divides and ridges. As the streams in crossing this belt descend to its eastern margin, their courses are marked by a series of rapids and cascades over hard rock channels like those in the Plateau. But between these gorges are flat divides, the continuation of the flat Coastal Plain surface, underlain by weak rocks, sand and clay, a part of the Coastal Plain sediments.

The total area of the Fall Belt as mapped, Fig. 1, is approximately 1,100 miles. Its greatest width is in the vicinity of Richmond. In the southern part of the State it is about twice as wide as in the northern part, its average width in the northern part of

the state being four miles, and in the southern part nine miles. Its average altitude is about 300 feet. The highest parts of the Fall Belt are near the Potomac with altitudes of 400 feet or more. Southward the surface gradually declines in altitude to 200 feet or less in the southern part of the State. Its total length in Virginia is 175 miles.

There is no possibility of the occurrence of oil or gas in the Fall Belt. Crystalline rocks floor the valleys, and the veneer of Coastal Plain sediments between the valleys is thin averaging but a few scores of feet.

THE BLUE RIDGE.

The Blue Ridge, often grouped with the Piedmont Plateau under the designation "Older Appalachians," trends across the west-central part of Virginia in a southwesterly direction and easily forms the most conspicuous topographic feature within Virginia. Its total length in the State is 280 miles, and its total area as mapped in Fig. 1 is approximately 3,500 square miles. Northeast of Roanoke the Blue Ridge is a narrow strip of country to the Maryland line with an average width of 12 miles, but southwest of Roanoke it gradually broadens into a plateau surmounted by mountain ridges so that at the State line it has a width of 68 miles. Its average width southwest of Roanoke in Virginia is 16 miles and its narrowest part is in the vicinity of Roanoke with a width of only 4 miles.

At Harpers Ferry the altitude of the Blue Ridge is less than 1,000 feet, but southward it increases in height rapidly with individual peaks near Luray attaining altitudes of more than 4,000 feet. Between Luray and Roanoke the average altitude of the Blue Ridge is about 3,000 feet with the individual ridges and peaks rising from 3,500 to 4,000 feet. Mt. Rodgers and Whitetop south of Marion in Smyth County possess altitudes of 5,719 and 5,520 feet respectively, the highest points in Virginia.

The northern Blue Ridge in Virginia is cored with crystalline rocks, Catoctin greenstone, Proterozoic in age, intrusive into the Blue Ridge batholith of quartz monzonite probably Archeozoic

in age. South of Roanoke pre-Cambrian gneisses and schists predominate. Siliceous Lower Cambrian sediments form the western flank of the Blue Ridge, locally extending to its crest and deeply mantling the crystallines beneath. Originally they extended across the Blue Ridge and connected with the Lower Cambrian belt of the western Piedmont. The series consists of three formations, the Unicoi formation, the Hampton shale and the Erwin quartzite (6) (Fig. 4).

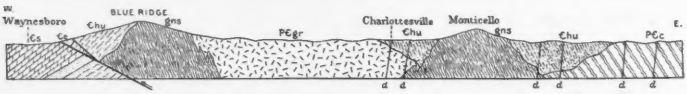


FIG. 4. Generalized geologic section across the Blue Ridge and western Piedmont in central Virginia. Length of section about 38 miles.

PCgr, Pre-Cambrian quartz monzonite gneiss; *PCc,* Pre-Cambrian schists; *gns,* Catoctin greenstone; *Chu,* Hampton and Unicoi formations; *Ce,* Erwin quartzite; *Cs,* Shady dolomite; *d,* dikes.

The Unicoi formation consists of arkoses, conglomerates, quartzites and schists. The materials were derived chiefly from the older crystallines and have a total thickness of 1,750 feet or more. The formation has been pronouncedly altered and deformed. Carbonaceous matter is lacking.

Overlying the Unicoi formation are dark-gray shales, slates and interbedded thin sandstones constituting the Hampton formation. In northwestern Virginia the formation is 400 feet thick and in southwestern Virginia 600 to 800 feet or more thick. The rocks have been profoundly crumpled and deformed.

The Erwin is composed of massive white resistant quartzite forming the western foothills of the Blue Ridge. The formation is 500 to 1,000 feet in thickness. It is nearly everywhere folded and faulted, and locally the brittle rock has been so subjected to pressure that it is brecciated and slickensided.

The general absence of carbonaceous matter from the rocks composing the Blue Ridge, the crystalline character of the basal rocks, and the intense folding, crumpling and faulting which the

overlying formations have experienced preclude the possibility of finding oil or gas in this province.

THE GREAT VALLEY.

Geography.—The Valley of Virginia extends southwestward through western Virginia for more than 300 miles from the Maryland boundary on the north to the Tennessee state line on the south. On the east it is flanked by the Blue Ridge, and on the west by the Alleghany ridges. The region averages 12 to 20 miles in width with a total area as mapped (Fig. 1), of 4,300 square miles.

In the northern part of the State the width of the Valley is very uniform averaging 18 to 20 miles, but in southwestern Virginia its width varies considerably due to spurs from the neighboring mountains projecting into the Valley. In eastern Botetourt County and northeast of Roanoke the Valley is very narrow and it is again similarly constricted southwest of Roanoke and northeast of Marion. Elsewhere it has a width averaging about 16 miles.

The altitude of the Valley ranges from 500 feet to 2,500 feet. At the Maryland line its altitude is 500 to 600 feet rising gradually southwestward to 1,800 to 2,000 feet in southern Augusta County. In the vicinity of Lexington it is 1,200 feet and around Roanoke about 1,000 feet in altitude. In Wythe County average altitudes of 2,500 feet are attained. Southwestward the Valley declines gradually to an altitude of about 2,000 feet at the Tennessee line.

In Lee County an extension of the Great Valley of Tennessee lies between Wallen Ridge and Stone (Cumberland) Mountain. In its topography, structure and stratigraphy it is closely allied to the Great Valley and hence is usually regarded as a part of the Great Valley Province. Beginning as a very narrow valley near Big Stone Gap, it widens to six miles and maintains essentially this width into Tennessee. It is largely a rolling lowland 1,500 to 1,800 feet above sea level, drained by Powell River.

TABLE I.

TABLE OF FORMATIONS OF WESTERN VIRGINIA.

	Southwestern Virginia		Middle-Western Virginia		Northwestern Virginia	
Pennsylvanian	Harlan formation					
	Wise formation					
	Gladeville sandstone					
	Norton formation					
	Lee formation					
Mississippian	Pennington formation					
	Newman formation		Greenbrier formation			
	Maccrady formation	Grainger formation	Maccrady formation (Absent in most places)		Pocono series	Purslane formation
	Price formation		Price formation			Rockwell formation
Devonian	Catskill formation		Catskill (Hampshire) formation	Kimberling shale	Catskill (Hampshire) formation	
	Chemung formation / Big Stone Gap Shale		Chemung shale and sandstone	Jennings formation	Jennings formation	Chemung shale and sandstone
	Portage shale	"Chattanooga"	Portage shale			Portage shale
	Genesee shale		Genesee shale			Genesee shale
	Romney shale (Absent in most places)		Romney shale (Absent in many places)		Romney shale	Hamilton sandstone and shale
						Marcellus shale
						Onondaga shale
	Oriskany sandstone	Hancock limestone Giles formation	Oriskany (Monterey) sandstone		Oriskany sandstone	
	Helderberg limestone		Helderberg limestone		Helderberg limestone	
Silurian	Cayuga formation	Rockwood formation	Cayuga formation	Lewistown formation	Cayuga series	Tonoloway formation
						Wills Creek formation
						McKenzie formation
	Clinton formation		Clinton formation		Clinton series	Keefer sandstone
						Rose Hill formation
	Clinch sandstone		Clinch sandstone		Tuscarora sandstone	

	Southwestern Virginia		Middle-Western Virginia	Northwestern Virginia
Ordovician	Sequatchie ("Bays") formation		Sequatchie formation	Juniata formation
	Martinsburg ("Sevier") shale		Martinsburg shale	Martinsburg shale
	Moccasin limestone / Tellico sandstone / Athens shale		Liberty Hall limestone	Chambersburg limestone
	Holston marble	Chickamauga limestone	Murat limestone	
	Stones River limestone		Stones River limestone	Stones River limestone
	Knox dolomite			Beekmantown limestone
				Conococheague limestone
Cambrian	Nolichucky shale		Natural Bridge limestone	
	Maryville limestone	Honaker limestone		Elbrook limestone
	Rogersville shale			
	Rutledge limestone			
	Watauga shale	Russell formation	Watauga ("Buena Vista") shale	Waynesboro shale
	Shady dolomite		Shady dolomite ("Sherwood limestone")	Tomstown limestone
	Erwin quartzite		Erwin quartzite	Erwin quartzite
	Hampton shale		Hampton shale	Hampton shale
	Unicoi formation		Unicoi formation	Unicoi formation
Pre-Camb.	Granite, greenstone and other crystallines			

Stratigraphy.—The Valley is underlain by Cambrian and Ordovician formations, although rocks of later age are not entirely absent, particularly those of Silurian age. The stratigraphic sequence is remarkably complete, with more than 20 formations represented. Stratigraphically the southwestern Virginia section is a part of the southern Appalachian region, the northwestern Virginia section is related to the northern Appalachian region, so that middle-western Virginia is the critical area in the inter-

pretation of the history of the entire Appalachian Province. The total thickness of the Cambrian and Ordovician formations of southwestern Virginia is about 15,000 feet, of middle-western Virginia 13,100 feet, and of northwestern Virginia 16,650 feet. It is beyond the scope of this study to discuss the various formations in detail; however, the accompanying tables present the salient features of the several formations of early Paleozoic age in western Virginia(7).

Four distinct phases of sedimentation are recognized in the Cambrian and Ordovician strata of western Virginia. These are in ascending order, (1) the arenaceous Lower Cambrian strata, (2) the dolomitic, pure and argillaceous limestones characteristic of Middle and Upper Cambrian and early Ordovician, (3) the Martinsburg shale of late Ordovician age, and (4) the sandy sediments of closing Ordovician age. The sediments are predominately calcareous and arenaceous with argillaceous strata prominent locally, but in general subordinate, and with but a relatively insignificant proportion of carbonaceous sediments.

Structure.—The early Paleozoic formations of western Virginia exhibit typical Appalachian structure characterized by the well known compressed and overturned folds and thrust faults of large displacement. Compression, however was not so pronounced as to induce metamorphism although shales locally have been altered to slates as in the Martinsburg, and the shales and standstones of the basal Cambrian, Unicoi formation, are largely shists and quartzites. Some of the sandstone formations above the basal Cambrian are chiefly quartzite, as the Erwin.

Both folds and faults trend northeast-southwest and are very persistent. Individual folds and faults may extend 50 miles or more. The faults may show displacement of several miles, such as the Pulaski fault where the displacement is at least nine miles. (8). In southwest Virginia seven major faults are recognized, together with a number of minor breaks.

The overturning of the folds toward the northwest has produced prevailing southeasterly dips at angles of 45° or more, and successive formations, although often of considerable thickness, outcrop within short distances across the dip and persist long distances as parallel bands in the direction of strike.

TABLE II.

LOWER PALEOZOIC FORMATIONS OF NORTHWESTERN VIRGINIA.

Period		Formation		Thickness Feet	Description
Ordovician	Upper Ordovician	Juniata formation		200±	Soft, red, sandy shales and red sandstone.
		Martinsburg shale	Upper and Lower Maysville	450±	Yellow and gray arkosic sandstones with thin bands of gray shale.
			Eden	1,000±	Yellow and greenish shales with calcareous and shaly sandstones.
	Middle Ordovician		Utica and Trenton	1,100±	Dark gray and black carbonaceous shale with calcareous shale and thin limestones near base.
		Chambersburg limestone		400	Thin-bedded, dark blue to black argillaceous limestone.
		Stones River limestone		900±	Thick-bedded, pure, dove and gray dolomitic limestone.
	Lower Ordovician	Beekmantown limestone		2,300±	Bluish-gray, finely laminated magnesian and pure fine-grained limestone (Stonehenge member at base).
Cambrian	Upper Cambrian	Conococheague limestone		1,650±	Dark blue magnesian limestone, oolite, laminated and conglomeratic limestone.
	Middle Cambrian	Elbrook limestone		3,000±	Blue and gray limestone and calcareous shale.
		Waynesboro shale		900−	Purplish sandy shale with mottled blue limestone and flaggy sandstone.
	Lower Cambrian	Tomstown limestone		1,000±	Blue-gray to dark-gray, glistening, coarse, massive dolomite.
		Erwin quartzite		500	Massive, white quartzite.
		Hampton shale		400+	Dark-gray, sandy shales and slates and thin sandstones.
		Unicoi formation		1,750–2,000	Slates, schists, sandstones, conglomerates, arkoses and quartzites.
Proterozoic		Catoctin schist		1,000+	Grayish-blue greenstone (altered diabase) with masses of irruptive granite.

TABLE III.

LOWER PALEOZOIC FORMATIONS OF MIDDLE-WESTERN VIRGINIA.

Period		Formation		Thickness Feet	Description
Ordovician	Upper Ordovician	Sequatchie formation		200–300	Red sandstones and sandy shales.
		Martinsburg shale	Upper and Lower Maysville	800–1,400	Gray shale, with sandy beds above and calcareous beds below.
			Eden		
			Utica and Trenton		
	Middle Ordovician	Liberty Hall limestone / Athens sh.		1,000±	Fine-grained, dark-blue limestone with darker argillaceous, knotty limestone beds, and calcareous shale increasing in importance upward.
		Murat limestone		125–	Massive, gray, coarsely crystalline, rather pure limestone.
		Stones River limestone		50±	Massive and thin-bedded, dark-blue, magnesian and pure limestones with laminated, mottled limestone and pure dove layers.
	Lower Ordovician	Natural Bridge limestone		3,500+	Chiefly heavy-bedded, gray and light blue, magnesian limestones with thin siliceous laminae conspicuous on weathered surfaces. Beds of white and pinkish dolomite and calcareous sandstones, thin to massive, locally developed.
Cambrian	Upper Cambrian				
	Middle Cambrian	Watauga ("Buena Vista") shale		600–900	Purplish shales with green, yellow and brown bands and mottled blue limestone
	Lower Cambrian	Shady ("Sherwood") dolomite		1,800	Light-gray to bluish-gray dolomite with some dark and bituminous limestones and dark shales.
		Erwin quartzite		500–1,200	Thick to thin beds of white quartzite with some dark shale.
		Hampton shale		500–800	Dark-gray, sandy shales and slates and thin arkosic sandstones.
		Unicoi formation		2,000±	Dark shale, thin-bedded gray sandstone, shaly sandstone and massive pebbly, white and ferruginous sandstone.
Proterozoic		Catoctin schist		1,000+	Grayish-blue greenstone (altered diabase).

Oil and Gas possibilities.—The Great Valley has never been regarded with favor as prospective oil territory. The few wells that have been drilled have with a single exception "come in dry." It is well known that the geologic conditions are unfavorable for the commercial occurrance of either oil or gas. In the first place the early Paleozoic formations of the region have little carbonaceous shale to supply hydrocarbons. The Hampton shale formation has bands and layers of black shale, and the Martinsburg formation in its lower part contains some black shale. Both of these formations have been so compressed that slaty cleavage

TABLE IV.

LOWER PALEOZOIC FORMATIONS OF SOUTHWESTERN VIRGINIA.

Period		Formation		Thickness Feet	Description
Ordovician	Upper Ordovician	Bays sandstone	Sequatchie formation	350–400	Red sandstone and sandy shale with a little limestone.
		Martinsburg ("Sevier") shale	Maysville	1,200±	Gray, sandy shale in upper part with blue calcareous shale and occasional beds of impure limestone below. Reedsville shale
			Eden		
			Trenton		Cathcys limestone, Cannon limestone
	Middle Ordovician	Moccasin limestone		400±	Impure reddish limestones and calcareous shales (Upper Black River) above, with thin-bedded, shaly and dove limestone (Lowville) below.
		Tellico sandstone		300±	Thin-bedded, generally red sandstone and sandy shale (Up. Blount).
		Athens shale		1,000±	Black, carbonaceous shales passing upward into blue calcareous shales with sandy shales above (Blount).
		Chickamauga limestone	Holston marble	100±	Coarse, granular, light-gray limestone (Lower Blount).
			Stones River limestone	1,000±	Thin, argillaceous, fine-grained, mottled, blue limestone and pure, dove limestone, overlain locally by black calcareous shale (Chazy).

Period		Formation		Thickness Feet	Description
Ordovician	Low. Ord.	Knox dolomite		4,000±	Thick beds of dolomite interbedded with thin beds of blue, magnesian limestone and massive beds of chert.
	Up. Cam.				
Cambrian	Middle Cambrian	Nolichucky shale		250–400	Greenish to olive calcareous shale, sandy shale and thin shaly limestones.
		Honaker limestone	Maryville limestone	500–600	Massive, mottled and laminar blue and gray limestone.
			Rogersville shale	0–100	Blue to brown calcareous shale.
			Rutledge limestone	240–300	Sandy shale below and dark, impure, magnesian limestone above.
		Russell formation	Watauga shale	500±	Purplish, sandy shale and sandstone with impure limestone beds.
	Lower Cambrian		Shady dolomite	1,800±	Massive, gray, glistening dolomite with white chert and arkosic sandstone and bands of red to white sandy shales.
		Erwin quartzite		500±	Chiefly light-brown shaly and flaggy sandstones with drab to black shale and vitreous quartzite.
		Hampton shale		600–800	Dark-gray and black shales, slates, ferruginous carbonate, and interbedded thin sandstones.
		Unicoi formation		2,000+	Massive quartzose and feldspathic sandstones and quartzite with conglomerate and interbedded shales.

is characteristic, and the associated rocks are not suitable structurally to retain oil if the shales once yielded hydrocarbons.

Compression has reduced the porosity of such formations as the Erwin and Juniata, which might serve as reservoir rocks, and aqueous metamorphism has further decreased the pore spaces of some of the formations in converting them into quartzite.

Extensive faulting to which the strata have been subjected would afford leakage surfaces for the escape of accumulating oil or gas. The anticlines developed during the periods of mountain

folding have been deroofed during the long period of erosion subsequent to the folding. In many places the anticlines have become valleys and the synclines mountains. The folding and profound erosion have resulted in the formations outcropping repeatedly in short distances permitting either oil or gas to migrate up the dip and escape at the surface as erosion progressed.

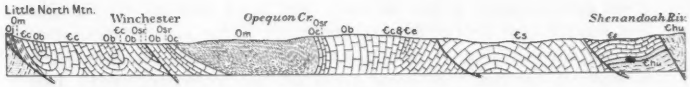


FIG. 5. Geologic section across Valley in northern Virginia. Length of section about 22 miles.

Chu, Unicoi formation and Hampton shale; *Ce,* Erwin quartzite; *Cs,* Shady dolomite; *Ce,* Elbrook limestone; *Cc,* Conococheague limestone; *Ob,* Beekmantown limestone; *Osr,* Stones River limestone; *Oc,* Chambersburg limestone; *Om,* Martinsburg shale; *Oj,* Juniata formation.

The fixed carbon content of most of the coals of the Valley fields of Virginia is so high as to indicate that neither oil nor gas will be found in strata associated with the coal. The coal is chiefly semi-anthracite with fixed carbon ranging above 65 per cent. Due to regional change westward the coals of the western part of the Virginia Valley coal fields in Bland and western Wythe counties are lower in rank and have been classified as semi-bituminous. The fixed carbon content of these coals, judging from the few analyses available, falls below 60 per cent. Under the isocarb theory oil or gas may be found in regions where deformation has not advanced the rank of the coal above 60 per cent in fixed carbon. However the structural conditions in this part of the Valley coal fields are similar to the conditions characterizing other parts of the Valley and are as unfavorable for the accumulation and storage of oil or gas as elsewhere in the Valley (8).

An oil seep in the vicinity of Rose Hill in extreme southwest Virginia in Powell Valley has long been known and about four years ago a well was drilled to a depth of about 300 feet in the

vicinity. The occurrence was so interesting and unusual and attracted so much attention that Mr. Charles Butts of the United States Geological Survey examined the area in May, 1923 (9). The driller's log runs as follows:

> Started through gray shale and went through this to a depth of 71 feet, when from 18 to 24 inches of green sand was found with a good showing of oil; then to a depth of 185 feet greenish-gray shale was found. A green sand of about 4 feet followed, with good showing of oil. The well was left over for two days and one night, during which time oil rose and overflowed casing. After going through this sand I found red shale to depth of 220 feet, then found 9 feet of dark oil-bearing sand. This sand was apparently full of oil but very hard, and oil did not flow from this sand; then found red shale for a distance of about 30 feet, then a very green shale to a depth of 285 feet, then went into a gray sand 18 feet, which was brittle, not hard like 9-foot sand, and was full of oil. Every bailer dropped into hole to clean the well would come out one half to two-thirds full of oil. After going through this sand, salt water was found at depth of 303 feet which rose in casing to a height of 200 feet.

The rock succession of the region ranges from Cambrian to Pennsylvanian the oil coming from the Clinton formation. The Clinton strata consist of soft green shale with thin layers of sandstone, red or chocolate colored shale, and thin, fine-grained, green sandstone. The outcrop of the Clinton rocks is about a square mile in area and triangular in outline, and lies at the bottom of a valley surrounded on three sides by ridges rising 300 feet or more above the bottom of the valley and composed of the lower part of the Knox dolomite, a formation that normally underlies the Clinton at a depth of a mile or more, (see Tables IV and VII). The older rocks have been driven from the southeast over the younger rocks to the northwest along a nearly horizontal fault surface. The overridden Clinton formation extends an unknown distance in all directions underneath the older mass of rocks. The outcrop of the Clinton rocks is due to the removal by erosion of the overlying rocks, forming a "window." Farther southwest another window occurs where Clinton iron ore has long been mined. The structure of the Clinton in the Rose Hill window is anticlinal with the strike of the low fold extending

west-northwest. The most favorable locality for drilling as determined by Mr. Butts is within a mile or so east, west, northeast and southwest from the present well.

Examination of the oil by the United States Geological Survey indicates that it is low in viscosity, opaque to transmitted light, dark green in reflected light, with kerosene-like odor. Its specific gravity is 0.815 at 23°C (41.8° Baume).

THE ALLEGHANY RIDGES.

Geography.—The Alleghany Ridges and Great Valley are frequently referred to as the Newer Appalachian Mountains in contradistinction to Blue Ridge and Piedmont, which are often designated as Older Appalachians inasmuch as they were folded in Pre-Cambrian and early Paleozoic times.

The province expands in width from southwest to northeast. This expansion takes place principally northeast of New River. At New River the belt is about 25 miles wide, expanding northward to 45 miles on Potomac River and averaging 40 miles wide. Due to irregularity in the position and direction of the Virginia-West Virginia line this expansion is largely in West Virginia, the width of the belt on the northern boundary of the State being only 14 miles. The southern part of the belt of Alleghany Ridges is only 15 to 20 miles wide and lies almost wholly in Virginia. The total length of the province in Virginia is 340 miles, approximately, and its total area is about 6,000 square miles.

In the northern part of the Alleghany Ridges province northeast of New River the trend of the valleys and ridges is about N 30°E. In this part of the province there are three more or less continuous prominent and parallel mountain ridges,—Little North Mountain on the East, Great North Mountain and Shenandoah Mountain on the west. A fourth, a continuous high ridge, the Alleghany Front, forms the western boundary of the State in Highland, Bath and Alleghany counties. Between these main mountain masses other ridges that are high and prominent are found but they are relatively short.

The Alleghany Ridges southwest of New River are not so

prominent or continuous as those to the northeast and their trend is quite different, being mostly N. 65° E. Only one, Clinch Mountain, stands out as a bold ridge forming the backbone of this mountain belt. It begins in Tazewell County and crosses the southern boundary of the state at a distance of 80 miles from its origin. Northwest of Clinch Mountain other prominent ridges, more or less broken, with different names in different parts of southwest Virginia, are Copper Ridge, Wallen Ridge, and Powell Mountain. Farther west Stone Mountain forms the eastern boundary of the Appalachian Plateau.

The mountains of western Virginia range up to 4,500 feet or more above sea level with average elevations between 3,000 and 4,000 feet. The intermontane valleys are but little higher than the floor of the Great Valley.

Stratigraphy.—The Alleghany Ridges are composed of strata of Silurian, Devonian and Mississippian age. Cambrian and Ordovician strata are not absent but do not predominate as in the Valley region, and Silurian strata are much more prevalent than in the Valley. In northwestern Virginia 13 formations above the Ordovician are represented, having a total thickness of 12,600 feet. In middle-western Virginia 11 formations are recognized totaling 7,400 feet in thickness, and in southwestern Virginia the sequence is both elaborate and complicated with a total of 16 formations, having a thickness of 6,800 feet.

The Silurian opens with the deposition of sand forming the Tuscarora (Clinch) sandstone. The middle and upper Silurian sediments are arenaceous and argillaceous in character. In the early Devonian calcareous strata were laid down followed by Oriskany sands. These were followed by black muds represented in the black shales of the Romney, Genesee and Portage formations. The upper part of the Devonian is chiefly arenaceous with deposition of much arkosic material, except in the extreme southwest Virginia where deposition of black shale took place continuing into Mississippian. The early Mississippian sediments possess much the same character as the Late Devonian, but in mid-Mississippian lime mud succeeds the arenaceous strata, followed by

TABLE V.

UPPER PALEOZOIC FORMATIONS OF NORTHWESTERN VIRGINIA.

Period		Formation			Thickness Feet	Description
Mississippian	Lower Mississippian	Pocono series	Purslane formation		300±	Thick-bedded, coarse-grained white sandstone with layers of quartz conglomerate and shale.
			Rockwell formation		500±	Coarse-grained, soft, arkosic sandstone, fine conglomerate and buff, hackly shale.
Devonian	Upper Devonian	Catskill (Hampshire) formation			3,000–4,000	Chiefly red, micaceous sandstone and shale with some yellow, green and gray sandstones and shales.
		Jennings formation	Chemung member		2,800	Argillaceous and arenaceous shales alternating with arkosic and micaceous sandstones with conglomerates locally.
			Portage	Parkhead member	400–600	Arenaceous shale alternating with bluish thin to thick sandstones with conglomerates developed locally.
				Woodmont member	1,200–1,600	Argillaceous, olive-green shale with a few thin sandstone beds below, argillaceous and arenaceous shales with many thin sandstone beds above.
			Genesee member		100–	Black, argillaceous, platy shale.
	Middle Devonian	Romney shale	Hamilton member		1,000±	Gray, argillaceous, fissile shales with thin beds of sandstone below, and gray, hackly shales with thick sandstone beds above.
			Marcellus member		100–200	Black, fissile shales with thin bands of black argillaceous limestone in lower part.
			Onondaga member		100–200	Dark fissile shales with lenses of black, knotty, compact, fossiliferous, argillaceous limestone.

Period		Formation		Thickness Feet		Description
Devonian	Lower Devonian	Oriskany sandstone		60–400		Gray to white and blue calcareous and siliceous, coarse sandstone and conglomerate.
		Helderberg limestone	Becraft member	100	300	Gray, impure, crystalline limestone.
			New Scotland member	100		Thick to thin beds of dark-gray, coarse-grained limestone, alternating with dark, knotty, siliceous limestone.
			Keyser member	100		Massive, compact, dark-colored, nodular limestone below, with thin-bedded, shaly, laminated, blue limestone above.
Silurian	Upper Silurian	Cayuga series	Tonoloway formation	400±		Finely laminated light-gray limestone and gray calcareous shale.
			Wills Creek formation	450–500		White and red thin sandstones alternating with thin, gray shales and laminated, argillaceous limestones. Lower part of formation (50–250 feet) red and green sandstone and shale (Bloomsburg member).
			McKenzie formation	200±		Gray, argillaceous limestone and calcareous shale becoming arenaceous upward in formation.
	Middle Silurian	Clinton series	Rochester formation (Keefer sandstone)	100–		Pure, white, quartzitic and conglomeratic sandstone.
			Rose Hill formation	400±		Olive-green, yellowish and reddish shales alternating with thin-bedded, yellow and ferruginous sandstones.
	Low. Silurian	Tuscarora sandstone		200–300		Massive, white, coarse sandstone and conglomerate.

arenaceous and argillaceous sediments of late Mississippian. The accompanying tables give the major features of the middle and upper Paleozoic formations of western Virginia.

Structure.—The structure closely compares with that of the Valley Province. The greater relief is due to the presence of the more resistant arenaceous strata characteristic of the middle and upper Paleozoic formations. Close folding and overturning of folds with thrust faults and steep southeast dips are the prevalent structures.

The folds extend for many miles and generally terminate with sharp pitch to be replaced by other folds on either side. The folding is not so intense in the mountain section as it is in the Valley. It progressively increases in intensity towards the Blue Ridge, so that overturning of the folds decreases toward the west and northwesterly dips increase in proportion. Some of

TABLE VI.

UPPER PALEOZOIC FORMATIONS OF MIDDLE-WESTERN VIRGINIA.

Period		Formation				Thickness Feet	Description
Mississippian	Upper Mississippian	Greenbrier limestone				350±	Light-blue limestone in thick beds with bands of brownish-red shale and red sandy shale.
	Lower Mississippian	Pocono	Maccrady formation (Absent in most places)			75–	Green and red shale and gray sandy shale.
			Price sandstone			100±	Coarse, arkosic sandstone with conglomerate.
Devonian	Upper Devonian	Jennings formation	"Kimberling shale"	Catskill (Hampshire) formation		1,500–1,800	Chiefly red sandstone and shale.
				Chemung member		3,000–3,800	Gray shales with arkosic and micaceous sandstones and conglomerates.
				Portage	Parkhead member		Gray, arenaceous shale with thin to thick gray sandstones and conglomerates locally.
					Woodmont member		Olive and gray, argillaceous and arenaceous shales with thin sandstone beds.
			Genesee member			100±	Black, argillaceous, fissile shale.

Period		Formation		Thickness Feet	Description
Devonian	Middle Devonian	Romney shale (Absent in places)		1,000–0	Dark-gray to black, fissile shale and thin sandstones, locally with Onondaga, Marcellus and Hamilton fossils. Absent in places. Thins toward southwest.
	Lower Devonian	Oriskany ("Monterey") sandstone		25–200	Dark, granular and crumbly, massive sandstones with shaly sandstone and locally shales and cherty limestones with iron ore.
		"Lewistown" formation	Helderberg limestone	100±	Massive, dark-gray and blue limestone locally cherty and iron bearing. Probably absent in places.
Silurian	Upper Silurian		Cayuga formation	200±	Massive, vitreous, white to gray sandstone, weathering red, with thin, dark and graphitic shale partings and some impure limestone.
	Middle Silurian	Clinton formation		400–650	Soft, green and reddish shales, thin to thick sandstones, red ferruginous quartzites and iron ore beds. Massive sandstone at base (Cacapon), and hard, slabby, light-gray quartzite at top (Keefer).
	Lower Silurian	Clinch sandstone		200–350	Massive, light-gray to white, coarse sandstone and conglomerate.

the ridges are anticlinal, such as Great North Mountain, and others are synclinal, as Alleghany Front, but the prevalent type of structure is uniclinal with steep dip, such as Clinch Mountain with southeast dip and Stone Mountain with northwest dip.

Faulting is as prevalent and typical as in the Valley. The

TABLE VII.

UPPER PALEOZOIC FORMATIONS OF SOUTHWESTERN VIRGINIA

Period		Formation		Thickness Feet	Description
Pennsylvanian	Lower Pennsylvanian	Pottsville series	Harlan formation	0–800	Massive, arkosic sandstone and conglomerate at base with arkosic sandstones, siliceous shales and thin coal beds above.
			Wise formation	0–2,600	An alternation of arkosic and micaceous sandstones with siliceous shales and coal beds.
			Gladeville sandstone	100±	Coarse-grained, arkosic, thick-bedded, cross-bedded sandstone and conglomerate.
			Norton formation	225–1,500	An alternation of arkosic and micaceous sandstones with siliceous shales and coal beds.
			Lee formation	800–1,800	Massive conglomerate at top with siliceous shales, arkosic sandstones and conglomerates with coal beds below.
Mississippian	Upper Mississippian	Pennington formation (Upper Chester)		1,000±	Chiefly gray to greenish shale with some sandstone and thin conglomerates. Thick sandstone at base and locally at top.
		Newman formation	Glen Dean Gasper St. Genevieve St. Louis	830±	Shaly and oolitic limestone with chert in lower beds, and calcareous shale.
	Lower Mississippian	Grainger formation	Maccrady shale (New Providence and Warsaw)	40–50	Fine-grained, light-gray sandstone and greenish and reddish shales.
			Price sandstone (New Providence)	180±	Greenish and micaceous sandstones with bluish, greenish and gray sandy shales.
Devonian	Upper Devonian		Catskill formation	100±	Red sandstone and shale. Locally absent.
			Chemung formation	2,000±	Gray shales with arkosic sandstones and conglomerates. Absent in extreme southwest Virginia.
		"Chattanooga" shale	Big Stone Gap shale	1,000±	Black, fissile shale below passing upward into gray and greenish, fissile shale.
			Portage shale		
			Genesee shale	200±	Black, fissile shale.

Period		Formation		Thickness Feet	Description
Devonian		Romney shale (Absent in most places)		10–0	Black shale. Absent in most places except a thin layer at base of Genesee.
	Lower Devonian	Hancock limestone Giles formation	Oriskany sandstone	0–200	Massive chert, green phosphatic and calcareous white, red and gray sandstone, siliceous limestone, and siliceous iron ore. Absent in extreme southwest Virginia.
			Helderberg limestone	0–100+	Sandy, cherty, fossiliferous limestone. Absent locally.
Silurian	Upper Silurian	Rockwood formation	Cayuga formation	125±	Laminated, magnesian and sandy limestones and calcareous, gray sandstones with some conglomerate and thin iron ore.
	Middle Silurian		Clinton formation	250–500	Green and red shales and sandstones, red ferruginous quartzites, and iron ore, with a hard slabby, gray quartzite at top (Keefer).
	Lower Silurian	Clinch sandstone		250–450	Coarse-grained, white, quartzose sandstone.

faults were originally low-angle overthrusts but the fault planes have been tilted and flexed in subsequent warping so that they possess steep inclination. Many of the faults can be traced long distances. The displacement may amount to several miles and in places erosion has removed the overthrust rocks forming "windows" through which the younger rocks beneath appear.

Oil and Gas possibilities.—The Appalachian Ridges province is quite as unfavorable as prospective oil territory as The Great Valley. No occurrence of oil or gas in any quantity is known in the region, and seeps are absent. The same adverse factors that characterize the Valley Province obtain here. Dark shales however are far more prominent than in the Valley. The Romney, Portage and Genesee shales and the Big Stone Gap shale of southwest Virginia, the so-called "Chattanooga" shale, are

prevailingly black, carbonaceous shales. Such shales furnish hydrocarbons in oil territory. Porous sandstones suitable as reservoir rocks are found in stratigraphic relations with the shales. Thus the arenaceous, medium to coarse grained sandstones of the Jennings formation overlie the Middle Devonian black shales but unfortunately the intense folding to which they have been subjected and subsequent erosion lead to their outcropping within short distances permitting free migration to the surface of volatile substances that might be formed. Erosion has deroofed the anticlines nearly everywhere, and synclinal and uniclinal ridges are prevalent topographic features, not suitable for oil and gas retention. Although the ends of the folds still preserve their roof rocks to act as "cap rock" yet the steep pitch characteristic of Appalachian folds would permit the migration of hydrocarbons upward along the axis of the fold to higher places where erosion has exposed porous strata that might contain oil. Fig. 6. illustrates the structural and stratigraphic conditions in the Appalachian Ridges.

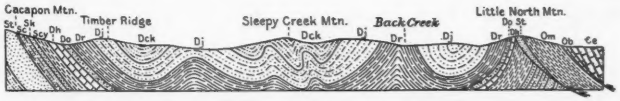


FIG. 6. Structure section across the Alleghany Ridges in northern Virginia. Length of section about 15 miles.

Ce, Elbrook limestone; *Ob*, Beekmantown limestone; *Om*, Martinsburg shale; *St*, Tuscarora sandstone; *Sc*, Clinton formations; *Sk*, Keefer sandstone; *Scy*, Cayuga formations; *Dh*, Helderberg limestone; *Do*, Oriskany sandstone; *Dr.*, Romney shale; *Dj*, Jennings formation; *Dck*, Catskill (Hampshire) formation.

THE APPALACHIAN PLATEAU

Geography.—The Appalachian Plateau occupies extreme southwest Virginia. Only a small part of the plateau enters Virginia however, for most of the plateau in the central Appalachian region lies in the eastern parts of Kentucky and West Virginia. The plateau enters Virginia in Tazewell County from West Vir-

ginia and extends southwestward through Lee County. In Lee County and western Wise County, Stone Mountain forms the rugged westward facing escarpment of the plateau. Farther east a prominent ridge on the southeast of the broad, flat-topped Powell Mountain marks the boundary, but farther northeast the plateau surface grades into the Allegheny Ridges province without marked topographic break.

The total area of the Appalachian Plateau in Virginia is about 1,550 square miles. Its length from northeast to southwest is approximately 140 miles, and its average width northeast of Lee County is about 23 miles. It is narrowest in southwest Lee County where it embraces only the width of Stone Mountain, and widest in Buchanan County with a total width of 32 miles.

In Virginia the Appalachian Plateau is a maturely dissected upland averaging over 2,000 feet in altitude. The region is extremely rugged so that it is often described as mountainous. The principal water courses are only a few miles apart and are separated by ridges that rise 500 to 1,500 feet above them. The ridges are steep-sided, winding and irregular with many lateral spurs. Flat lands are limited to narrow linear tracts along the stream and ridge tops.

Stratigraphy.—The rocks underlying the Appalchian Plateau in Virginia belong to the Pottsville series of the Pennsylvanian system. Many years ago they were divided by Campbell into five formations, named as follows: Lee formation, Norton formation, Gladeville sandstone Wise formation and Harlan formation. (See Table VII). The strata are highly siliceous sandstones and shales, composed of quartzose, arkosic and micaceous materials, with which are interbedded numerous coal beds.

The Lee formation ranges in thickness from about 800 to 1,800 feet. It is composed of sandstone, shale and conglomerate. A massive conglomerate 100 feet or more thick marks the top of the formation nearly everywhere, and in places thick conglomerate members form the central and basal parts of the formation. Between these conglomerates are found sandstones alternating with shales which carry the coal beds.

The Norton formation is from 825 to 1,500 feet thick. It is a succession of alternating arkosic and micaceous shales and sandstones with numerous and well-known coal beds.

The Gladeville sandstone maintains an average thickness of 100 feet over a large part of the Appalachian Plateau in Virginia. It is a coarse, quartzose sandstone and conglomerate. Its massive character is characteristic and makes it an excellent key horizon in mapping.

The Wise formation departs but little in its lithologic characters from the Norton formation. It is thickest in the western part of the area ranging from 2,000 to 2,600 feet. Interbedded with its arkosic sandstones and micaceous shales are numerous beds of workable coal.

The Harlan formation is composed of arkosic sandstone and conglomerate and siliceous shales with thin interbedded coal beds. The formation is present only in the higher summits of the plateau. The erosional remnants are rarely more than 200 feet thick and of very limited area.

Structure.—The southeast boundary of the plateau is marked by one or more overthrust faults throughout much of its course, called the Hunter Valley fault zone. Where faults are absent the rocks are upturned at a steep angle representing the transition into the folded Appalachian structure. From Dickenson County southwest the northwest margin of the field is bounded by the Pine Mountain fault zone. The origin and mechanics of these major faults have been described by Wentworth (10).

Within a short distance of the disturbed margin on the southeast the strata underlying the plateau flatten out into a gentle northwestward dip of 50 to 75 feet per mile to the vicinity of Pine Mountain (Fig. 7). This is the prevalent structure of the plateau but is locally modified by certain pronounced flexures such as the Middlesboro syncline extending from Buchanan County southwest into Tennessee, and the Pine Mountain anticline extending from Buchanan County southwestward into Kentucky. In addition to these larger flexures smaller folds of anticlinal, dome and synclinal types are found throughout the region. Such

a fold is the Sourwood Mountain anticline about seven miles long in southeastern Dickenson and nothern Russell counties. Most of the smaller folds are not designated by name but are well

FIG. 7. Geologic section across the Appalachian Plateau in Virginia showing stratigraphic and structural conditions. Section about 27 miles long. (Adapted from Dickenson and Wise counties reports, Va. Geol. Surv.)

Chk, Honaker limestone; *Cmp,* Price and Maccrady formations; *Cnl,* Newman formation; *Cpn,* Pennington formation; *Cle,* Lee formation; *Cnr,* Norton formation; *Cg,* Gladeville sandstone; *Cws,* Wise formation.

shown by structure contours on the maps of the recent coal reports of the southwest Virginia coal district published by the Virginia Geological Survey.

Oil and Gas Possibilities.—The economic possibilities of the region so far as oil and gas are concerned have been discussed at length by Eby and need not be repeated here (11). His conclusions are based on the isocarb theory. It is shown that there is a progressive decrease in carbonization of the coals from the northeast to the southwest. This condition is attributed to the development of the Hunter Valley and Pine Mountain fault zones which affected the southwestern part of the Virginia coal field and early relieved the lateral pressure to which the region had been subjected, hence the coals have not been so compressed and therefore are of lower carbon rank than those in Buchanan County and Tazewell County northeast of the faulted area, where long continued and intense compression was not relieved by faulting. As a result the coals of Lee County in the extreme southwest part of the district have a fixed carbon content figured on a pure coal basis of about 60 per cent., which increases northeastward to more than 65 per cent. in Buchanan County.

Oil is rarely found above the 62.5 per cent. isocarb and is not

often found above the 60.0 per cent. isocarb which makes it unlikely that oil will be found anywhere in the Appalachian Plateau of southwest Virginia. Inasmuch as gas follows the isocarb theory less closely than oil it is possible that commercial quantities of gas may be found under suitable structural conditions in the region. Gas seepages have been reported from shallow water wells in central Buchanan County and from other localities. Diamond drilling has revealed small quantities locally and one deep well, 2,150 feet, in Wise County yielded a small flow of gas.

CONCLUSION.

An examination of the geology of Virginia with reference to the occurrence of commercial quantities of oil or gas reaffirms the prevalent conception that neither oil nor gas will be found in significant quantities within the State. It is probable that in the Coastal Plain gas originating in buried peat and shell beds of shallow depths may be found in quantity sufficient for local household use. But the absence of extensive deposits of organic matter and of suitable trap structures precludes the likelihood of finding commercial quantities of either oil or gas in this province.

The Piedmont and Blue Ridge provinces, underlain chiefly by ancient crystalline rocks, offer no prospect of success in the frequent attempts to find oil or gas. The Triassic red beds which cover large areas of the Piedmont afford no encouragement to the driller because of the prevalence of faulting and of the absence of organic materials to supply hydrocarbons either from their strata or from associated strata.

The Great Valley and Alleghany Ridges likewise offer little prospect of success in oil exploration. While strata rich in organic materials are not lacking yet the intense compression, pronounced deformation and prolonged erosion to which the rocks have been subjected have reduced to a minimum the possibilities of accumulation and retention of oil or gas. Compression and erosion have appreciably deminished the proportion of reservoir rocks while prolonged erosion has not only deroofed suitable

structures, but has also brought about repetition of outcrops of the steeply dipping rocks within short distances, and deformation has afforded numerous avenues of escape along fault surfaces. The well recently drilled near Rose Hill in southwest Virginia has revealed under unusual stratigraphic and structural conditions the only known occurrence of oil in either province, and it is doubtful if the quantity of oil here is sufficient to be of commercial importance.

The isocarbs drawn on the coal beds of the Appalachian Plateau indicate that the prospect of obtaining commerical quantities of oil in this province is unfavorable, but the suitable structural conditions afford a possibility of obtaining gas in some quantities. The fact that a number of wells have yielded gas although in small quantities is likewise encouraging.

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A LEAD ORE CONSISTING OF NATIVE LEAD, LEADHILLITE AND LITHARGITE.[1]

EARL V. SHANNON.

THE occurrence of native lead has been noted from time to time in several mines in the vicinity of Hailey in the Wood River Mining region of Blaine County, Idaho, particularly in the Jay Gould mine. All the mines from which the native metal has been reported are included in a small area near the head of Bullion Creek in the Mineral Hill District about 5 miles south of west of the town of Hailey. Most of the reported occurrences date back many years to the days of more active mining in the region but Mr. C. P. Ross of the U. S. Geological Survey informed the writer some two years ago that ore was being shipped from a prospect known as the Arizona in which the lead was apparently all in native form. Subsequently a lot of specimens of this ore was obtained for the National Museum by Mr. Ross and these (catalogue No. 92066) form the basis for the following description.

The specimens consist of what appears to be a greenish-black argillaceous rock seamed and veined with whitish fractures along which the lead occurs. The metal is in small blebs and particles which are soft and easily scratched with the finger nail revealing their metallic luster and sectility. These tarnish and quickly lose their metallic luster and become dull and inconspicuous. For this reason an attempt to polish the metal for study under the reflecting microscope was unsuccessful. No other metallic material was recognized in the section so ground. Upon handling the specimens as a whole the amount of visible lead seems insufficient to account for the high apparent specific gravity. The metal forms hackly grains embedded in a soft white matrix or

[1] Published by permission of the Acting Secretary of the Smithsonian Institution.

larger rounded masses surrounded by a bright red substance. A sample of the lead was analyzed in the Museum laboratory and the results, recalculated after deducting gangue are as follows:

ANALYSIS OF NATIVE LEAD.

Lead (Pb)	98.66
Silver (Ag)	.33
Copper (Cu)	.07
Iron (Fe)	.94
Zinc (Zn)	trace
Mercury (Hg)	none
Arsenic (As)	none
Antimony (Sb)	none
	100.00

Heated in a closed tube, the metal fuses quietly and does not give any volatile sublimate.

The crusts surrounding the cores of lead are orange-red in color, have adamantine luster and show well defined cleavage in one direction. In high index oils the material becomes practically opaque owing to coating of the grains by precipitation of lead iodide. In lower index iodine-free oils the mineral appears as flat plates of orange-yellow color lying on the perfect cleavage and showing two other cleavages at right angles to this cleavage and to each other. The mineral shows very high index, high birefringence and is not pleochroic. The plates are uniaxial and negative with the optic axis perpendicular to the perfect cleavage. Heated in the closed tube it fuses quietly to a yellow glass. All of these properties unite to prove that this mineral is the relatively rare monoxide of lead, lithargite.

The whitish material surrounds the lithargite layer or serves as a matrix for smaller hackly grains of lead where there is no lithargite. It is very soft and has a perfect cleavage in one direction. Tiny cavities are lined with druses of microscopic crystals too small for measurement. This mineral also forms cleavages up to several millimeters broad which are colored by dark pigmenting material and resemble the gangue rock into which they shade. This is the most abundant lead mineral in the ore.

Under the microscope it shows very high refractive index and lies on the single perfect cleavage which is nearly perpendicular to the acute bisectrix. The grains are biaxial and negative with the axial angle, $2E$, almost zero. The dispersion is strong, $r < v$. Heated in the closed tube it fuses and froths up into a sponge of yellow glass and gives no sublimate. It is easily soluble with effervescence in cold dilute nitric and hydrochloric acids. The nitric acid solution gives no reaction for chlorine and there remains an undissolved residue of lead sulphate. This mineral is unquestionably leadhillite.

An occasional grain of native silver is to be seen under the binocular microscope, either attached to the border of a mass of native lead or isolated in granular leadhillite. The two native metals in contact with each other recall the "half breeds" of juxtaposed native copper and silver from Lake Superior.

Galena occurs in very small amount and its relation to the native lead is not clear. In one case it forms a very fine grained microscopic border line on either side of a very narrow layer of calcite which penetrates the rock. A few isolated and minute pyrite grains were seen embedded in the gangue rock remote from the other minerals.

There is little to be learned regarding the genesis of the native lead through a study of the specimens and it is impossible to say whether the lead is the latest mineral of the series and formed by the reduction of leadhillite through lithargite or the reverse. The latter seems more plausible and the corroded cores of metal seem to be remnants of the process which produced the leadhillite and lithargite by reaction with the lead. The silver apparently was in solid solution in the original lead but separated during alteration as nuclei of native silver. Just why the lead was deposited in native form cannot be surmised nor whether it is a primary (hypogene) mineral like the galena or due to secondary (supergene) processes.

Occurrences of native lead are rare and, of those reported, only a very few are demonstrably natural. In the present case there can be no question as to the validity of the material. The asso-

ciation with the relatively uncommon minerals lithargite and leadhillite is of interest, as is the fact that material of this composition was actually mined and shipped as ore.

The writer wishes to express his thanks to Mr. C. P. Ross for the specimens of this ore and for the privilege of describing them.

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MICROCHEMICAL TESTS IN THE IDENTIFICATION OF OPAQUE MINERALS.

H. E. McKINSTRY.

THE twenty-odd years that have elapsed since William Campbell [1] first applied the methods of metallographers to the study of ores have abundantly justified his prophecy:

> . . . investigations of this kind will serve to render intelligible many of the relations between the minerals of ore deposits which have hitherto been obscure.

But in spite of the rapid development of that science which we still describe by the circumlocution "study of polished sections," the technique of identifying ore minerals under the microscope still falls far short of perfection, and many are the errors that have crept into the literature because of incorrect determinations.

During the last ten years we have relied mainly on schemes based on color and on behavior with certain etching reagents. Students, particularly those whose eyes are sensitive to delicate color distinctions, are able to recognize with surprising accuracy minerals with whose behavior they have had an opportunity to become thoroughly acquainted. But when less familiar species are encountered, the investigator, after applying his etching tests, often closes his tables with some misgiving, places a question mark after his conclusion and casts about for a definite check or independent means of attack.

One check of this sort, the method recommended in the texts, is to gouge out fragments from the back or edges of the specimen and make blowpipe tests. This method is highly satisfactory if the mineral occurs in large areas and the specimen is un-

[1] "The Microscopic Examination of Opaque Minerals," ECON. GEOL., vol. 1, p. 751, 1906.

mounted; more difficult if the grains are small or scarce; and cannot be used at all if the chip is mounted in sealing wax or bakelite. The new method of mounting[2] adds so much to the quality of surface, and so facilitates numbering, filing and the relocation of desired points in the field, that its disadvantages are far outweighed in any laboratory where large numbers of specimens are handled.

Recently a number of very useful aids to identification have been developed. Talmage's quantitative measure of hardness[3] has proved decidedly useful, and his color-comparison device[4] awaits only perfection of the apparatus which will admit of more delicate matching. Electrical conductivity[5] has been of considerable service, and R. D. Harvey's[6] more accurate methods of measurement offer great promise. The polarizing microscope, adapted to reflected light, described by Königsberger[7] as early as 1908, but long neglected, has been resurrected and has proved most useful[8] but there is still a crying need for the investigation of the optical properties of the so-called opaque minerals.

Recent work has shown that microchemical tests for most elements can be made as satisfactorily as the older blowpipe tests with the advantage that they require much smaller amounts of material and involve less damage to the specimen.

A number of investigators have been working along this line.

[2] Short, M. N., "The Preparation of Polished Sections of Ores," ECON. GEOL., vol. 21, p. 655, 1926.

[3] Talmage, S. B., "Quantitative Standards for Hardness of the Ore Minerals," ECON. GEOL., vol. 20, p. 531, 1925.

[4] "The Diagnostic Value of Color in Polished Sections," ECON. GEOL., vol. 20, p. 168, 1925.

[5] Davy and Farnham, "Microscopic Examination of the Ore Minerals," p. 123, New York, 1920.

Kerr, P. F. and Cabeen, C. K., "Electrical Conductivity of Ore Minerals," ECON. GEOL., vol. 20, p. 729, 1925.

[6] Unpublished Doctor's Thesis, Harvard University, 1927.

[7] "Uber einen Apparat zur Erkennung und Messung optischer Anisotropie undurchsichtiger Substanzen und dessen Verwendung," *Centralblatt für Min. usw.*, pp. 565, 597, 1908. Fully translated in Winchell, "Optical Mineralogy," p. 465, Van Nostrand, New York, 1909.

[8] Sampson, Edw., "Note on the Determination of Anisotropism in Metallic Minerals," ECON. GEOL., vol. 18, p. 775, 1923.

Professor Lindgren at Mass. Institute of Technology, Putnam and Roberts at Yale and Dr. Short of the U. S. Geological Survey will all be able to offer valuable contributions from the fund of their experience. Short's conscientious and painstaking work will, when ready for publication, be far more accurate and comprehensive than anything that the present writer can submit. It is the purpose of the present paper merely to present without further delay the results of a limited investigation in order that they may be at the disposal of other workers. In doing this, no claim of originality is made. While some of the tests described are new and others are adaptations of tests familiar in qualitative chemistry (but not, so far as known, employed in micro-chemistry), many are taken from the standard texts.[9] They are here described for the sake of completeness and largely because no published directions are sufficiently explicit to be of immediate use to the inexperienced student.

Usually some experimentation has been necessary to determine whether the tests must be applied to acid, alkaline, or neutral solutions, since the texts are often reticent on this point. In some cases it was necessary to test the sensitiveness of the reactions in order to make sure that they could be carried out in solutions of the available concentrations and that the precipitates and colorations were recognizable in minute quantities.

ACKNOWLEDGMENTS.

The writer has made free use of an unpublished report[10] by K. K. Landes with notes by R. W. Goranson, and their results have been checked. M. N. Short has reviewed this paper and offered many valuable suggestions and criticisms. Professor L. C. Graton, under whose direction the work was done, has at all times been keenly interested and his advice has been most stimulating.

[9] Chamot, "Elementary Chemical Microscopy." Wiley, New York, 1921.
Behrens-Kley, "Mikroscopische Analyse." Voss, Leipsig, 1921.
Grey, "Practical Chemistry by Micro-Methods," Cambridge, Eng., 1925, is more elementary than the foregoing works but describes a few useful methods.

[10] Report on Research, Laboratory of Economic Geology, Harvard University.

BRINGING THE MINERAL INTO SOLUTION.

In order to produce the precipitates or colorations characteristic of a given element it is necessary first to dissolve or decompose the mineral. In the case of readily soluble minerals which occur in grains sufficiently large to avoid contamination from adjoining foreign species, this causes no difficulty. The mineral may be dissolved either:

(1) By placing a drop of reagent on the polished surface itself by means of a loop of platinum wire or

(2) By scraping the mineral with a needle and transferring the powder to a glass slide for solution.

The writer prefers in most cases to use the former method, since less delicate manipulation is required and the process of solution can be watched through the microscope to make sure that portions of foreign material just below the original surface or in adjoining grains are not dissolved. Where the grain to be tested is smaller than a single drop, it may be isolated by the following method: the surface is coated with an insoluble substance of which a portion over the grain is removed and the reagent applied. Greases and waxes such as vaseline or paraffine are difficult to remove completely from the grain and usually leave the surface oily so that the reagent does not wet it. Canada balsam is fairly satisfactory. The balsam is "cooked" until brittle on cooling, then poured melted on the polished surface. It is transparent and the grain may be seen through it. A small drop of potassium hydroxide is then applied. This renders the film friable so that it can be scraped clear in the desired location with a needle-point, after which the reagent is applied to the cleaned surface. A simpler medium, however, is collodion, used in the form sold under the trade-name "New Skin" with varied spellings. The film of collodion is applied and, when dried, a hole is pricked through it with a needle. It is necessary to have the collodion of the proper consistency, otherwise it does not stick tightly to the surface around the hole and allows the reagent to work out under the edge of the film where it may encounter undesired minerals.

If the solution is carried out on the polished surface, the tests may in some cases be made on the drop in place. Where conspicuous precipitates are formed, as for example the brilliant pink of the dimethyl glyoxime test for nickel, this is entirely satisfactory. In some cases, however, the color of the mineral or its roughened surface may obscure the test. Furthermore it is often necessary to evaporate the solvent and redissolve the residue in water or another reagent. In such cases the tests can be carried out more visibly and with less damage to the specimen if the drop is transferred to a glass slide. This can be done by means of a capillary tube. Such tubes may be made in quantity by heating and drawing out pieces of soft glass tubing to the diameter of a fine needle and breaking the tubular glass hair into pieces about 10 cm. long. One end is placed in the drop which then passes by capillary attraction into the tube. The liquid is then deposited on the slide by blowing gently through the tube.

M. N. Short and K. K. Landes prefer to remove a fragment from the surface of the section to a glass slide and there dissolve it. This is done by scraping the surface with a bevelled point made by grinding off a sewing needle so that the termination makes an angle of about 60 degrees with the long axis. When some of the powder has been loosened it is touched with the moistened tip of a stick of orange-wood or the point of a sharpened toothpick to which it adheres. The pointed stick is then dipped in a drop of water on the glass slide and the powder is left in the drop. The water may then be evaporated and the mineral dissolved in the proper reagent. This method has the advantage that heat may be applied to the solvent to aid solution. Slides of Pyrex glass have the advantage that much less care is required to prevent them from cracking on heating than is the case with ordinary glass.

The solvent usually used is nitric or hydrochloric acid; the reagent in which the mineral is soluble will already have been determined in the course of etching tests, or if the identity of the mineral is suspected, may be found by consulting a text on microscopic determination. Some minerals insoluble in the standard

reagents yield to concentrated acid, aqua regia or fuming nitric acid. Potassium hydroxide or potassium cyanide dissolve certain minerals which are unattacked by acids, but the excess of the salt or the presence of CN ions sometimes obscures reactions. Where cyanide has been used it is often possible to roast off the cyanogen but this may leave a difficultly soluble residue. On the whole it is more satisfactory to use acids where possible.

Some minerals such as tetrahedrite and enargite dissolve readily in nitric acid when two electrodes of platinum wire connected with a current of one or two volts are immersed in the drop. In cases where the grain is too small to give space for two electrodes but is surrounded by a mineral which is a good conductor, it has been found satisfactory to coat the surface immediately about the grain with colloidion, then apply a drop of acid, insert one terminal in the acid and allow the other to touch the surface of the surrounding mineral outside the coated portion. In this way very minute grains of tetrahedrite surrounded by chalcopyrite have been dissolved in nitric acid and tested for copper and antimony.

TESTING THE SOLUTION.

The technique of adding reagents, filtering and decanting drops is fully described by Chamot [11] and will not be repeated here. Fry [12] gives a list of the optical properties of salts, data which are useful in the identification of precipitates under the polarizing microscope.

Within certain limits which will be mentioned, tests for the following elements have been found satisfactory:

Ag	Ni	Cu
As	Co	Au
Sb	Fe	Te
Bi	Pb	Zn

The following elements were not investigated by the writer:

[11] *Op. cit.*

[12] Fry, Wm. H., "Microscopic Determination of Inorganic Salts," U. S. Dept. Agric., Bull. No. 1108, 1922.

Cr	S	Tl
Ge	Se	U
Hg	Sn	V
Mo	Ti	W

A test for manganese is described which may prove satisfactory on perfecting technique. It consists in fusing sodium carbonate on the surface in a tiny electric arc and then making a bead test on platinum wire. This same method would be applicable to chromium, titanium and other elements which give colored beads. It might also be applied to the problem of getting into solution the difficulty identifiable minerals of the "hard insoluble" group.

TESTS FOR THE ELEMENTS.

Antimony.—By means of:

1. Cesium Chloride. Break down the mineral in nitric acid. The antimony is oxidized to Sb_2O_5, sulphur from sulphantimonite minerals remaining as a powder. The nitric acid *must* be driven off by gentle evaporation. Redissolve the residue in dilute hydrochloric acid. On opposite sides of the drop add crystals of cesium chloride and potassium iodide respectively. A brick-red precipitate indicates antimony. (But see Bismuth which gives a somewhat similar precipitate.)

N. B. If the nitric acid is not driven off, iodine is formed from the potassium iodide, blackening the solution and obscuring the color.

Sensitiveness: A fairly strong but not concentrated solution was found to give a precipitate when diluted with 80 parts of water but not with 160 parts.

Minerals: This test was successful with bournonite, breithauptite, jamesonite, polybasite, pyrargyrite, and stephanite.

2. Zinc and Platinum. Dissolve the mineral in nitric acid, take up the solution in a loop of platinum wire and allow liquid and wire to touch a piece of zinc. After a few minutes the platinum turns black from deposition of pulverulent metallic antimony. Test tried only with tetrahedrite, dissolving the mineral in acid heated on a glass slide.

3. Sodium Thiosulphate. A solution of antimony chloride and antimonyl chloride was evaporated (after acidifying with hydrochloric acid), along with a solution of sodium thiosulphate ("hypo"). On heating, the solution turned brown, indicating antimony. The test was successful with tetrahedrite but not so distinctive as the cesium chloride test (1, above).

Arsenic.—By means of:

1. Ammonium Molybdate. Dissolve the mineral in nitric acid, using electric current if necessary. To the drop of nitric acid solution add a drop of about the same size of 2 per cent. ammonium molybdate solution. Then heat gently until a ring of excess ammonium molybdate begins to form by evaporation around the edge of the drop. Then allow to cool, or preferably, cool with as little evaporation as possible by spraying the under side of the glass slide with water. Arsenic, if present, gives a canary yellow flocculent precipitate in the still-liquid part of the drop.

N. B. Evaporation should be stopped at such a point that on cooling there still remains a pool of liquid inside the white ring. If the whole drop turns white from crystals of the salt, redissolve in a drop of nitric acid and warm again. It is also possible to evaporate the original nitric solution almost, but not quite, to dryness. Then, on adding ammonium molybdate the precipitate forms without warming.

Minerals: This test was successful with arsenopyrite, enargite, tennantite, pearceite and smaltite.

Bismuth.—By means of:

1. Cesium Chloride. The procedure is the same as for antimony. The precipitate is of a much darker red color.

Minerals: This test was successful with native bismuth, bismuthinite and lillianite (the latter dissolved in aqua regia with electric current).

Cobalt.—By means of:

1. *Alpha Nitroso Beta Naphthol.* The mineral is dissolved in nitric acid, evaporated and dilute hydrochloric acid added. Then a large drop of naphthol solution is placed on a glass slide. The low surface tension of the acetic acid in which it is dissolved

causes the solution to spread out in a thin film on the glass. Now, a drop of the cobalt solution when placed on the film stands out like a rivet-head and turns blood-red. The reagent is made by dissolving 50 mg. of alpha nitroso beta naphthol salt in 2 cc. of acetic acid. (The concentration need not be exact.)

Sensitiveness: Tests were made on cobalt nitrate solution and it was found that the reaction takes place when the solution is too dilute for the pink color of cobalt-ion to be visible. The test is not interfered with by even an excess of nickel in the solution.

2. Ammonium Mercuric Sulpho-Cyanate. The mineral is dissolved in nitric acid, evaporated and redissolved in water. Add ammonium mercuric sulpho-cyanate. Dark blue prisms, usually in clusters, separate out.

N. B. The test drop must not be alkaline. It should be neutral or only slightly acid with acetic. On account of a tendency to supersaturation it is necessary to allow considerable time or evaporate gently. Nickel does not interfere except in excess.

This test is more dependent on proper concentration than (1) above.

Minerals: Successful with smaltite and cobaltite.

Copper.—By means of:

1. Ammonium Mercuric Sulpho-cyanate. Dissolve the mineral in nitric acid, using electric current or heat in the case of enargite and tetrahedrite. Evaporate, take up in water and then bring into contact with the test drop a drop of ammonium mercuric sulpho-cyanate solution. Yellowish-green, moss-like crystals, either in radiating groups or pointing inward from the margin of the drop separate out.

N. B. Potassium cyanide interferes with the test. If the mineral is dissolved in this reagent, the cyanogen must be roasted off. This renders the residue insoluble in water but it may be redissolved in very dilute nitric acid. Acetic acid may be used but is not very satisfactory. If the concentration of nitric acid exceeds about 10 per cent. the green crystals are soluble.

Sensitiveness: The test was successful in a solution of 0.05 per cent. copper sulphate, but the crystals formed very slowly.

Minerals: This test was successful with aikinite, bournonite, bornite, chalcocite, chalcopyrite, chalmersite, covellite, cuprite, enargite, tenorite, tennantite, and tetrahedrite.

In adding the reagent to the test drop, care must be taken not to have the reagent in excess. It is best to place the two drops side by side and allow them to merge.

2. Ammonium Sulpho-cyanate. When added to copper sulphate, ammonium sulpho-cyanate gives yellow crystals forming from numerous centers like the silver chromate crystals of the silver test. Not tried on any minerals.

3. Electrolysis: Two electrodes of fine platinum wire and a current of about two volts are used, and the test is made on the surface of the mineral on which is placed a drop of nitric acid. The anode touches the mineral outside the drop and the cathode is placed within the drop but off the surface. A dark sooty or smooth black coating forms on the cathode. The electrodes are removed from the test drop and both immersed in a drop of nitric acid on a glass slide. On reversing the current the copper is plated across to the other electrode and shows the color of a film of ordinary copper.

Minerals: Successful with tetrahedrite.

Gold.—By means of:

1. Stannous Chloride. Dissolve mineral in aqua regia. Add hydrochloric acid and stannous chloride solution. A precipitate black to various shades of red blue and purple (purple of Cassius), depending on the dilution, consists of finely divided gold.

Minerals: Successful with native gold but not with tellurides, since stannous chloride precipitates metallic tellurium from tellurious acid and this obscures the character of the gold. Successive applications of 1:6 HCl will remove all but traces of tellurious acid.

2. Thallium chloride. Dissolve the mineral in aqua regia and evaporate to dryness. Redissolve in nitric acid. Add a crystal of thallium chloride. A "yellow beard" of slender crystals forms around the added grain.

N. B. It is necessary to use a *nitric acid* solution.

Minerals: Successful with native gold but not with tellurides. Valueless in presence of tellurious acid.

Iron.—By means of:

1. Potassium Ferrocyanide. Dissolve the mineral in nitric acid in order to oxidize the iron to the ferric state. Add a drop of potassium ferrocyanide solution. Iron gives a blue coloration.

N. B. If copper is present in large excess the brown copper ferrocyanide may obscure the precipitate.

2. Ammonium Sulphocyanate. Dissolve the mineral in acid, evaporate to dryness, redissolve in water and add a drop of ammonium sulphocyanate. A strong red coloration is produced.

Sensitiveness: This test is very delicate and may be given by minerals containing only a trace of iron. The student should familiarize himself by experiment with the intensity of color to be expected and, if necessary, dilute the test drop with much water.

3. Ammonium Mercuric Sulpho-cyanate. The procedure is the same as (2) above. The color is obtained incidentally in testing for copper, zinc and cobalt in minerals containing iron when the sulphocyanide method is used for these metals.

Lead.—By means of:

1. Potassium Iodide. Dissolve the mineral in nitric acid. Evaporate nearly to dryness and take up in water. Add a crystal of potassium iodide. A precipitate of yellow hexagonal crystals indicates lead.

N. B. The solution should be slightly acid but not strongly so. If too much nitric acid is present the solution will be blackened by liberation of iodine.

2. Chromates. Dissolve the mineral in acid and add potassium chromate or bichromate. Presence of lead is indicated by a yellow colloidal precipitate.

N. B. A number of other metals give chromate precipitates and if present in large amounts may obscure the reaction. Silver gives a red precipitate; copper, orange; antimony, orange-yellow; iron, brick-red.

3. Zinc. Dissolve the mineral in nitric acid and add a grain of metallic zinc. Metallic lead grows about the zinc in dendritic crystals.

Sensitiveness: The precipitate forms in solutions containing 0.5 per cent. lead nitrate but not 0.05 per cent.

N. B. Silver behaves similarly but is not precipitated by metallic copper. See under Silver. The solution should not be too strongly acid.

Manganese.—1. Bead Test. Dissolve mineral in nitric acid on polished surface and add powdered sodium carbonate to absorb liquid. Take up the paste on a platinum loop. Heated in the strong oxidizing flame of a Bunsen burner this gives a strong blue bead.

Minerals: Successful with alabandite. For manganese minerals insoluble in acids the test is inapplicable. An experiment was made to determine the possibility of another mode of approach, using psilomelane: Two terminals of platinum wire were used and current was supplied from a small transformer designed for stepping down street current for a Silvermann illuminator. One wire was attached to a platinum terminal which touched the surface of the mineral. The other was attached to a platinum loop. Sodium carbonate in the form of a thin paste was placed on the surface of the mineral around the platinum wire and the loop was inserted into the paste. In the arc so formed the mineral surface was deeply etched and the soda turned black. The loop was heated in the Bunsen oxidizing flame with additional soda and the bead turned greenish-blue.

Nickel.—By means of:

1. Dimethyl Glyoxime. Dissolve the mineral in acid and make alkaline with a slight excess of ammonia, in order to precipitate, as hydroxide, iron which would otherwise interfere with the test. Place next to the test drop a drop of a solution of dimethyl glyoxime and merge the two drops. If nickel ions are present, a beautiful pink precipitate forms. This may be colloidal at first but after a few seconds acidular crystals form. This is one of the most familiar and satisfactory of all the microchemical tests.

Minerals: Successful with niccolite and pentlandite.

N. B. In the presence of copper and cobalt a yellow amorphous precipitate forms which may mask or prevent the formation of the true nickel

precipitate. Copper, according to Goranson [13] may be removed by adding zinc foil to a weakly acid drop. Cobalt may be removed by means of potassium nitrite.[14]

Silver.—By means of:

1. Ammonium Bichromate. A neutral, or preferably 0.1 per cent. nitric acid solution, is used and must be relatively concentrated in silver. Add a fragment of ammonium bichromate. The resulting coffin-shaped crystals of silver chromate and bichromate are dark red.

Sensitiveness: The precipitate is recognizable in a 0.05 per cent. solution of silver nitrate but not in 0.02 per cent. According to Short [15] the test works well in solutions as concentrated as 1:8 HNO_3.

2. Chlorides. Add hydrochloric acid to the nitric acid solution. In presence of silver a colloidal white precipitate forms.

Sensitiveness: The precipitate is visible in a solution containing 0.04 per cent. silver nitrate but not 0.004 per cent. Very delicate but not very distinctive.

3. Sulpho-cyanates. To either acid or ammoniacal solution add sodium or ammonium sulpho-cyanate. In presence of silver a white precipitate resembling the chloride is formed. This dissolves in "hypo" (sodium thiosulphate) when the solution is neutral or ammoniacal. (In acid solution the hypo is decomposed so that the precipitate of the silver salt is obscured.) The white precipitate turns black with ammonium polysulphide.

Sensitiveness: The precipitate is visible in silver nitrate solution containing 0.02 per cent. of the salt and barely visible in 0.001 per cent. solution.

4. Zinc. To a drop of silver nitrate solution add a grain of metallic zinc. Black fernlike crystals of silver grow out from the zinc. A small amount of nitric acid does not interfere with the reaction. A piece of bright copper wire will also precipitate silver.

[13] Landis, *op. cit.*

[14] Chamot, *op. cit.*, p. 413, gives details of this procedure.

[15] Personal communication.

N. B. *To distinguish silver from lead:* in nitric acid solution, put in a piece of copper. If nothing happens, silver is absent. Then put in a piece of zinc (not touching the copper—if it touches, a precipitate on the copper may form). A precipitate on the zinc then indicates lead.

Sensitiveness: Both zinc and copper precipitate silver in solutions of 0.04 per cent. concentration in silver nitrate, but not 0.004 per cent.

5. Developer. Soak a piece of blotting paper in photographic developer. If a drop of silver nitrate is placed on this it forms a black spot which may be bleached with a drop of potassium cyanide.

Interfering metals: Mercury gives a white spot which turns gray around the edge but this is insoluble in potassium cyanide. Lead (as acetate) does not interfere.

Sensitiveness: Successful with 0.04 per cent. solution of silver nitrate but with 0.008 per cent. only a faint gray spot appeared.

Tellurium.—By means of:

Cesium Chloride. Dissolve mineral in nitric acid, or if necessary, in aqua regia; evaporate and redissolve in dilute hydrochloric acid (strength 1:6). Add a crystal of cesium chloride. A bright lemon-yellow precipitate indicates tellurium. On adding a crystal of potassium iodide the precipitate turns brown. The yellow crystals are most easily visible in a polarizing microscope between crossed nicols with the light from the mirror cut off.

Minerals: Successful with calaverite and with a very small grain of hessite.

Zinc.—By means of:

1. Ammonium Mercuric Sulpho-cyanate. Dissolve the mineral in nitric acid or (sphalerite) in aqua regia. Dilute the solution and add an excess of ammonium mercuric sulpho-cyanate. White skeletal crosses and feathery crystals indicate zinc.

Minerals: Successful with sphalerite.

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DISCUSSION AND INFORMAL COMMUNICATIONS

THE ZONAL ARRANGEMENT OF MINERALS IN THE CORNISH LODES.

Sir: In this Journal[1] E. H. Davison tabulates the zones of the Cornwall lodes according to various authors. He notes that the several zones as tabulated really overlap; nevertheless, such a tabulation of the minerals is rather unsatisfactory, as the different zones in the table cannot but give the suggestion of so many "water-tight compartments."

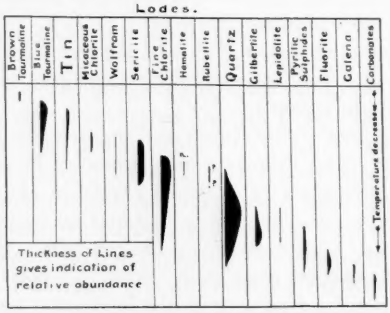

FIG. 1. Time Scale of Mineral Deposition in Cornish Lodes. Note: Position of wolfram estimated from work of E. H. Davison.

I would like to point out a method of diagrammatically representing the zonal arrangement of the minerals which was quite useful to me during my study of the Cornish lodes. On p. 455, Volume 18 of ECONOMIC GEOLOGY I wrote: "The table shows the apparent sequence of crystallization of the minerals in the lodes examined." Owing to an oversight in publishing, however, the table was omitted, but is given here (Fig. 1).

Each line represents the time and temperature interval over which that mineral crystallized; the width of the line represents

[1] ECON. GEOL., vol. 22, No. 5, 1927, pp. 475–479.

the relative amount of the mineral crystallizing out at different times during the crystallizing period. Hence from top to bottom of the diagram is a picture of the succession of minerals which *theoretically* should be met with in any lode channel in Cornwall at increasing depths. Similarly, if the granite is regarded as occupying a space towards the lower left-hand corner of the diagram, then the successive lines to the right *theoretically* represent the minerals which crystallize out in lode channels situated at successively greater distances from the granite surface.

Conversely, as the geo-isotherms do not remain stationary during the cooling of the granite mass, but become successively lowered throughout crystallization of the lode minerals, the diagram is also a picture of the order of mineral deposition at any point in the lode channel during crystallization of the lode solutions. Hence, theoretically, and in actual fact, it is quite possible for minerals of successively cooler temperatures of crystallization in the lode solution to be deposited ultimately at even the lowest depths of a lode channel and in the vicinity of the high temperature minerals, provided the geo-isotherms sink low enough, and the lode channel remains porous enough to allow permeation of solutions and crystallization throughout. This fact is often lost sight of by authors, the geo-isotherms apparently being regarded as practically permanent during mineral deposition. It is also because of this fact that the more usual tables of mineral succession lose their significance. Different authors may give divergent tables merely because they happen to have studied different parts of even the same lodes, whereas if attention were given to the *range* of crystallization of each mineral, there would be closer agreement.

J. A. DUNN.

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CHANGES IN THE OXIDATION OF IRON IN MAGNETITE.

Sir: In the May issue of the *Journal* Geoffrey Gilbert raises the question whether "oxidized magnetic" or "ferro-magnetic

ferric oxide," as Sosman and Posnjak originally named it, occurs in nature. I can assure him that it does, and in very large quantities.

I have recently been studying the so-called "titaniferous magnetite" forming great stratiform segregations in the upper part of the norite zone of the Bushveld Igneous Complex. It soon became apparent that in some of the most strongly magnetic varieties of the ore magnetite is absent, its place being taken by a very strongly magnetic form of ferric oxide that, except for the color of its streak, has all the properties of ordinary hematite.

I was fortunate in being able to get confirmation of my views as to the identity of the mineral from no less authority than Professor H. Schneiderhöhn, to whom I submitted specimens.

The magnetic ferric-oxide is in intimate intergrowth with ilmenite which occurs both in megascopic grains and minute oriented lamellae.

The specimens examined were all taken from the outcrop or immediately below it. It is probable, therefore, that the mineral is a product of the normal atmospheric weathering of magnetite. It will, however, only be possible to obtain confirmation of this inference when ore from the same segregations is obtainable from below water-level.

According to the investigations of Sosman, Posnjak and Miss Twenhofel, the interesting form of ferric oxide under discussion appears to be identical in atomic structure with magnetite, but has the chemical composition and the physical properties of hematite. To distinguish it from that mineral, and from martite, it is desirable that it should have a distinctive designation. "Ferromagnetic ferric oxide" is too long. "Oxidized magnetite" is misleading, as it contains no ferrous oxide.

I would suggest *maghemite*, but am quite prepared to withdraw this if anyone can suggest something more suitable.

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REVIEWS

The Principles of Petrology. By G. W. TYRELL. 8 vo., pp. 336. Methuen & Co. Ltd. London, 1926. Price $3.25.

This book was written as a textbook for advanced undergraduates, and supplementary reading by those engaged in applied geology. It is an elementary discussion of the fundamentals of petrology, as distinguished from petrography.

The book is unique in that it contains no reference to the older literature of the science. The influence of Harker and Holmes is most noticeable. That of Daly, Washington, Vogt, Goldschmidt, Lacroix, Niggli, Grubenmann and Rosenbusch is less apparent, while reference is rarely made to other writers of similar rank. It is disappointing to find that the number of illustrations for all classes of rocks drawn from English sources exceeds the combined number from American, German, French, and Fenno-Scandian sources.

The book is divided into three parts, dealing with igneous, sedimentary, and metamorphic rocks. Chapter II. treats of the forms and structures of the various types of intrusions, including several unusual types of dikes. Figure 11, inserted to explain the origin of the so-called "ring dike," is not convincing. It is surprising to find that all intrusive bodies in folded regions are attributed to "rapid passage along lines of regional tension," and that no mention is made of possible blow-pipe action or other means of magma transfer. Since this chapter aims at completeness, the intrusive bodies ethmolith (Solomon) and sphenolith (Burckhardt) might have been included. The phrases "differentiated intrusions" and "contrasted parts" are substitutes used for diaschistic dikes. No mention is made of aschistic dikes. The occurrence of metallic ores in amygdules is not mentioned.

Chapters III. and IV. discuss the composition and constitution of magmas and the formation of igneous rocks. Well explained line diagrams and concise description of the physico-chemical relations between the components of the magma make this portion very readable. The author subscribes to the views of Tamman and Doelter and Harker concerning super-cooling, while he is cognizant of views held by Oswald and Meirs; namely, that no crystallization occurs at the freezing point unless the solution is "seeded," but that if no inoculation occurs many

crystals appear between 37° and 55° below it. It is surprising to find that "the eutectic intergrowth of orthoclase and quartz produces the well-known rock graphic granite," despite the valuable contributions of Alling, Sosman, et al. to the contrary. In general, however, the physical chemistry of the binary and tertiary systems is well treated, but the importance of eutectic mixtures is over-emphasized.

In Chapter VI. the author adopts a classification of igneous rocks based on a mixture of rocks supersaturated, saturated, and subsaturated with silica. Accordingly, the rocks are not separated as minutely as by schemes using feldspars, but the adopted scheme is simpler, hence it is more teachable to beginning students. It is mainly a field classification, applicable chiefly to plutonic rocks, whereas the volcanic and dike rocks are placed in their proper position largely on the basis of color and according to their megascopic minerals.

Chapter VII. is devoted to the distribution of igneous rocks in space and time. The author includes such terms as series, tribe, clan, branch, and stem under the omnibus term "kindred" as the widest kind of grouping in which the igneous rocks show consanguineous chemical and mineral characters. He emphasizes the fact that the boundaries of petrographic provinces are vague and argues that the true spatial and temporal association of a kindred are with a certain geologic environment, and, finally, concludes that "on the whole alkalic kindreds do tend to be associated with epeirogenic, and calc-alkali kindreds with orogenic movements of the earth's crust."

In concluding Part I. the author speaks of hybrid rocks (p. 164) as those produced when xenoliths of country rock are partially dissolved in a magma. This definition applies more strictly to the migmatites of Sederholm, while the more generally accepted definition of a hybrid rock is that rock which is produced by the intermingling of two partially cooled magmas.

Part II. deals with secondary rocks in which the author confuses the reader by restricting the term "sedimentary" deposits to those formed by the deposition of solids carried in suspension. It is the opinion of the reviewer that such materials would be better termed "mechanical" sediments as contrasted with material deposited from solution by chemical or organic processes which are termed "chemical" and "organic." Chapter X. gives a concise treatment of residual deposits but no reference is made to the notable work of Harrassowitz on soil profiles. Chapter XI. discusses the mineralogical, textural, and structural characters of sedimentary rocks. There is no reference to the work done in America on the standardization of grade and class terms and methods of plotting mechanical analyses of sediments. It is surprising, indeed, to find no reference to Milner's valuable works on sedimentary petrography.

The old idea that all kaolinite is "due to the action of hot vapors containing boric and hydrofluoric acids on the feldspars of granite" is still advocated to the exclusion of all others. Weinshenk early held this view, but Reis, Lindgren, Bayley and others have proven that many deposits of kaolinite have resulted from the weathering of feldspar-rich rocks, especially pegmatites in which the tourmaline, topaz, fluorite, and tinstone occurred as original constituents.

Part III. is devoted to metamorphic rocks. The author follows Harker in refusing to recognize a distinction between regional and local metamorphism. The reviewer does not believe many will accept the conclusions drawn by Trueman and advocated by the author; namely, that "the ratio between the length and thickness of mica flakes (index of elongation) provides a rough index to the intensity of crystallization." In the author's classification of the metamorphic rocks he has discarded that of Grubenmann, and Eskola's later modification of the same, because in these classifications only those rocks in which recrystallization has been paramount have been treated. The scheme adopted in this text is an expansion of Holmes' tentative classification proposed in 1920.

The book concludes with four chapters dealing with the principal kinds of metamorphism and the products resulting from each, and a final chapter on metasomatism and the additive processes.

This volume is one which every student of rocks should own not alone because it is the only one of its kind in English, but also because it treats a difficult subject in an interesting and simple way. It should be regarded, however, only as a good introduction. It cannot replace the works of Erdmannsdörfer or Grubenmann. Unfortunately, the book has a physical make-up far inferior to its contents, being printed on coarse paper and cheaply bound.

R. S. POOR.

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BIRMINGHAM, ALABAMA.

The Geology of the Southern Part of the South Staffordshire Coalfield (South of the Bently faults). By T. H. WHITEHEAD and T. EASTWOOD. Memoir of the Geological Survey of England and Wales. London, 1927; xx + 198 pp., 13 plates, 5 text-figures.

This volume deals with a field that has yielded coal for over six hundred years and is not yet exhausted. Once, as its place names indicate, a thickly wooded country, the region is now the notorious Black Country of England.

The South Staffordshire coalfield is a roughly spindle-shaped area about 25 miles in length from north to south. It is divided into two

parts by a narrow down-dropped block between the two east-west Bentley faults. The southern division, described in this memoir, contains the well-known Thick or Ten-yard coal of South Staffordshire. North of the faults, the thick seam splits into members that decrease in thickness northward.

The coal, associated with spathic iron ores and fireclay, occurs in the Middle Coal Measures of the British Carboniferous, which rest unconformably on rocks that range from Cambrian to Upper Silurian and are overlain by a thick series of barren Upper Coal Measures, which, in turn, are unconformally overlain by Triassic. The coal-bearing rocks are intruded by dikes and sills of olivine basalt of undetermined age. It is rather remarkable that in a field so long worked, and described in a classic memoir by Jukes in 1859, the question whether the igneous rocks are older or younger than the faults is still in dispute.

By far the greater part of the volume is occupied with details of stratigraphy and structure that are of local rather than of general interest.

The memoir may be obtained for 6 shillings and sixpence from His Majesty's Stationery Office, Adastral House, Kingsway, W. C. 2, London, England, or, in the United States from The British Library of Information, 44 Whitehall St., New York.

F. L. RANSOME.

Grundlagen der Erdbebenkunde (Foundations of Seismology). By B. GUTENBERG. Pp. 189, 84 figs., 1 plate. Borntraeger Brothers, Berlin, 1927. Price, 6.60 marks.

The purpose of this excellent little book, which is published as Volume 12 of a series (Sammlung Borntraeger) of scientific works by different authors, is to state the underlying principles of the various subdivisions of the field of seismology, including the most important theories and opinions on the phenomena connected with earthquakes and the methods of investigating these phenomena, as well as the hypotheses which form the basis of the theories and their practical applications.

The book is divided into eight parts. Part I. is descriptive, containing nine chapters dealing with the effects of earthquakes at the earth's surface, on the surface of the earth itself, on artificial constructions of all kinds, and on men and animals, together with a description of the natural phenomena which accompany earthquakes. Part II. treats of the origin of earthquakes, containing chapters on such subjects as the periodicity of earthquakes and the relation of this periodicity to meterological phenomena; the nature of the forces which build up stresses in the crust (spannungserzeugende Kräfte) and the smaller periodic forces, such as rapid changes in atmospheric pressure, tidal forces, etc. (spannung-

sauslösende Kräfte) which can effect a release of the stresses already present by increasing them beyond the breaking point of the crustal material; the energy of earthquakes; the form and depth of the seismic focus; and the various kinds of earthquakes. Part III. deals with the geographical location of the chief seismic zones of the earth. Part IV. gives a brief description of the various types of instruments used to detect earthquakes, and a simple explanation of the theory underlying their construction. Part V. contains eleven chapters dealing largely with the interpretation of seismic data; the different types of earthquake waves, their time-curves, their manner of propagation and their velocities in the earth's crust and in the interior; surface waves and their significance in determining the nature of the material of the crust. Part VI. contains three chapters on the methods used to determine the location of the seismic focus, its depth, and the exact time the energy was released at the focus. Part VII. on "Seismic Crustal Unrest" describes briefly the causes of the small vibrations which are more or less continuously travelling through the crust. Among these causes may be mentioned the breaking of the waves along sea coasts, winds of high velocity striking trees, high buildings, etc., and the great machines of human industry. Part VIII. consists of a short chapter on the prediction of earthquakes and the protection of civilization from the catastrophic effects which severe quakes have brought about in the past.

The book is concluded with an excellent bibliography, which is confined to the best modern works on seismology, with the inclusion of a few of the most important writings of earlier authors.

The book is well written throughout, and contains a number of very helpful illustrations, diagrams and tables. It is to be hoped that the work can be translated into English, as it includes much material that is of value to the geologist and geophysicist, and the number of good books on this subject in English is surprisingly small.

H. W. Rose.

Yale University,
New Haven, Conn.

Grundzüge der praktischen Bodenkunde. By H. Stremme. Pp. 299, 6 figs., index. Gebrüder Borntraeger, Berlin, 1926.

In this book Stremme has ably presented the modern conception of the soil and the European schemes of soil classification. He reviews the work and theories of Dokutschajeff, Nabokich, Ramann, Glinka, Murgoci and others, and discusses these in the light of the soil knowledge of today.

Soil mapping is discussed with main reference to the work in Germany. There is no reference to the soil survey work in the United States or the

mass of detailed soil information there available. He points out that generalized maps can only be developed when sufficient detailed studies have been made available and criticizes the several general soil maps of Europe as being based on insufficient data. He repeatedly emphasizes the need for careful study of the whole soil profile from the surface soil to the underlying parent material, and discusses at length the various methods of soil sampling.

Considerable space is given to the consideration of virgin and cultivated soils, with an especially full and valuable discussion of the changes that are brought about by tillage and cropping, the cutting of timber and by excessive grazing. Soil erosion and the relation of tillage, cropping and manuring to erosion and fertility are presented.

The processes of weathering of the soil mass receive considerable attention, with discussions of the changes of feldspars to zeolites, the variations in chemical composition of colloids, base exchange phenomena, the migration and concentration of clays and other materials in the subsoils, and other features that differentiate the soil profile horizons.

Under the heading of "Climatic Soil Groups" he discusses the development of soil profiles and the A, B and C horizons. In this discussion and later in his description of certain soils, he differs from most European and American Edaphologists in not recognizing the existence of a B horizon unless there is an evident accumulation of sesquioxides. Even in his description of well developed Chernozems, with definite and obvious clay and lime accumulations in the subsoils, he refers to them as consisting of A and C horizons only!

His descriptions of soil profiles are rich in detail and are valuable additions to the accumulating fund of soil information. He has also set forth and defined a number of terms applicable to soil texture, structure, porosity, tilth, consistence, etc., that aid in interpreting the profile descriptions.

In his descriptions of typical soil horizons he uses the terms Chernozem, Podsol, Roterden, Rendzina, Braunerde, etc., that are primarily designations of color only. However, he states "The designation of soils by colors is not pleasing . . . and has caused great confusion in Germany." He does not, however, offer a substitute for this nomenclatural basis.

The book is a valuable addition to the rather meager literature dealing with the soil as a natural body, as a definite part of the earth's surface. The press work is excellent.

CHAS. F. SHAW.

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TUCSON, ARIZ.

Field Astronomy for Engineers and Surveyors. By DAVID CLARK. Pages 164, figs. 50. Constable and Co., Ltd., London, 1926. Price $3.50.

This little book is a compact account of the methods employed by engineers in locating points in areas in which they are making maps.

It discusses the astronomical principles involved in determining locations; describes the essential engineering instruments employed for this purpose, and outlines the methods employed in standardizing and using them and in correcting any errors to which they are found to be subject.

The principal part of the volume deals with the methods of making accurate observations in the determination of time, azimuth, latitude and longitude and explains the mathematical processes involved therein. The procedure of solving problems is illustrated by discussions of imaginary cases.

The book treats of all the methods that the surveyor is apt to need for locating himself and handles them in a very clear and concise manner.

W. S. B.

Linking Science and Industry. A Symposium compiled by HENRY C. METCALF. 206 pp. Williams & Wilkins, Baltimore, 1925. Price, $3.50.

This book gathers together sixteen lectures by as many authors, delivered as evening courses for executives at the Bureau of Personnel Administration. They deal with the relations of science, economics, and philosophy to business administration and personnel management.

SCIENTIFIC NOTES AND NEWS

Percy A. Wagner has recently been investigating fluorspar deposits in the red granite of the Bushveld Complex.

E. C. Andrews, Government Geologist of New South Wales, gave two lectures at Cornell University recently, and also at Columbia University, on the mining industry and structural geology of Australia.

Walter B. Jones has succeeded to the position of State Geologist of Alabama, left vacant by the recent death of Dr. Eugene A. Smith.

J. Morrow Campbell left London in October for a trip to Burma.

Herman Gunter was recently reappointed State Geologist of Florida.

E. E. Campbell, formerly general superintendent of the United Verde Extension, has been inspecting the Quebec gold and gold-copper districts.

Douglas Wright is examining the property of the McNeeley Holdings Company in the Red Lake area of northern Ontario, near the Howey gold mine.

J. B. Gowen, Jr., on the geological staff of the Anaconda Copper Mining Company, has gone to Poland, where the company has properties.

Arthur W. Jenks has gone to Colombia to conduct an examination of several mining properties there.

William Anderson, consulting engineer, has been making an examination of the Anaconda Kamiskotia property in northern Ontario, where there is a report of an important discovery.

C. A. Heiland, of the Colorado School of Mines, was engaged during the summer in making geophysical measurements of a magnetite deposit in the Caribou district, Colorado, for the U. S. Bureau of Mines.

J. Mason Jones has gone to Australia from England to undertake the leadership of an expedition organized by the Australian Commonwealth Government, to make further investigations as to oil possibilities in New Guinea and Papua.

E. G. Lawford, mining engineer of London, England, visited New York recently, and has now gone to Rio Tinto, Spain.

W. G. Woolnough, geologist of the Australian Commonwealth, has returned to Melbourne after completing preliminary examination of possible oil prospects in Queensland.

J. P. Rees, of Birmingham University, has gone to Johannesburg to take a position with the Transvaal Chamber of Mines.

W. W. Raymond, from McGill University, is in charge of underground work in the Central Manitoba Mines, Ltd.

E. T. Corkill is consulting engineer for the Brett-Trethewey Company, recently formed, with properties in Barnet Township, in the Kirkland Lake district of northern Ontario.

Raymond Brooks, recently general manager of exploration work in central Africa for the Rhodesian Congo Border Concession, is now located in New York City as consulting engineer, with an office at 27 Beaver Street.

E. de Hautpick has gone from London to Melbourne, to carry on geophysical exploration in Australia.

C. W. Rolfe, emeritus professor of geology at the University of Illinois, has offered a $250 prize for the most valuable contribution toward a new, better, or increased use of mineral resources in Illinois. Any work published between May 1, 1927, and May 1, 1928, or unpublished work, is acceptable if treating of deposits that show real present or prospective economic value.

D. I. Mushketov, Director of the Geological Survey of Russia, has been visiting the United States to study the organization of the National and State Geological Surveys. While in this country he gave addresses before several universities and societies relating to the geology of Central Asia and Turkestan and the organization of the Geological Survey of Russia. He sailed for England on November 16.

The Thirtieth Annual Convention of the American Mining Congress will be held at the Mayflower Hotel, Washington, D. C., on December 1, 2 and 3.

The Geological Society of America will hold its Fortieth Annual meeting in Cleveland, Ohio, December 29–31, 1927. The Society of Economic Geologists, Mineralogical Society, and Paleontological Society will hold meetings at the same time.

The U. S. Geological Survey has just published, in connection with the Columbia River irrigation project, five maps (at ten cents a copy) on a scale of one-half mile to the inch and five-foot contours, covering sixty miles of Clark Fork of the Columbia River and including Lake Pend Oreille.

I. C. White, known chiefly as the originator of the anticlinal theory in connection with petroleum, died at his home in Morgantown, West Virginia, November 24.

Leon Feuchere, a well-known mining geologist of Bisbee, Arizona, died October 28 at Long Beach, California.

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